UNIVERSIDAD SAN FRANCISCO DE QUITO

Colegio de Ciencias e Ingeniería

Benchmarking and Teardown Analysis of competition components from smartphones and tablets, aiming towards the development of STMicroelectronics and ST-Ericsson roadmap

Juan Fernando Fuentes Navarrete
Omar Aguirre, MSc., Director de Tesis

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HOJA DE APROBACIÓN DE TESIS

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Juan Fernando Fuentes Navarrete

Omar Aguirre, MSc.
Director de Tesis ______________________________

Lionel Trojman, Ph.D.
Miembro del Comité de Tesis ______________________________

René Játiva, Ph.D. (c)
Miembro del Comité de Tesis ______________________________

Ximena Córdova, Ph.D.
Decana Escuela de Ingeniería
Colegio de Ciencias e Ingeniería ______________________________

Quito, abril 2014

DEDICATORIA

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Resumen

El mercado de dispositivos móviles está creciendo de manera exponencial y también la necesidad de investigación y desarrollo de los fabricantes. En la última década los teléfonos inteligentes y tabletas han pasado de ser un bien deseado a un bien necesario. Para desarrollar dispositivos más pequeños, más rápidos y más baratos millones se invierten todos los días por las empresas que manufacturan. El estudio de análisis de la competencia se basa en todas las funciones asociadas y es esencial en el hardware y el software de cada dispositivo móvil. En el software son importantes sus funciones particulares tales como pantalla, memoria, cámara, conectividad, batería, etc. El estudio de Software es en su mayoría estándar, algunas aplicaciones gratuitas y otras pagadas. Estas pruebas se utilizan para comparar el comportamiento de cada dispositivo móvil a su predecesor o similar. Fabricantes buscan para mejorar la capacidad de sus componentes para ofrecer mejores productos y esto se puede hacer sólo mediante el estudio de la competencia. El análisis de hardware es esencial para entender las nuevas tecnologías usadas, el proceso de soldadura, construcción, tipo de componente, reducción de la superficie, y otros, para comparar precios y ser capaz de estimar el costo total de la producción por parte de la competencia. Del mismo modo comprendemos la calidad y el rendimiento de los componentes de la competencia para mejorar y perfeccionar las soluciones de ST- Ericsson. Costo y capacidades son las características más importantes para un componente y darán información crucial utilizada para mejorar los procesos de fabricación comprendidos en esta tesis.

Abstract

Mobile device markets are growing exponentially and so are the research and development needs of manufacturers. In the last decade smartphones and tablets had pass from a wanted good to a needed good for almost everyone. To develop smaller, faster and cheaper devices millions are invested everyday by manufacturing companies. A study of competition analysis is based in all associated features and is essential in both hardware and software of each mobile device. In software are important their particular functions such as display, memory, camera, connectivity, battery, etc. Software benchmark is mostly standard, some with free applications and others paid. These tests are used to compare the behavior of each mobile device to its predecessor or similar. Manufacturers search to improve competition capabilities to offer better products and this can be done only by studying the competition.

In the analysis of hardware is essential to understand the new technologies used, bonding process, construction, type of package, area reduction of different components, and others to compare prices and be able to estimate the total cost of manufacture by the competition. Similarly we understand the quality and performance of the competition components to improve and refine solutions ST-Ericsson.

Cost and capabilities are the most important features for a component and will give crucial information used to improve manufacturing processes. By the end of this thesis a general and specific comprehension of a mobile device and its characteristics will allow to improve design and solutions for smartphones and tablets.

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INTRODUCTION

Company Presentation (ST-Ericsson)

ST-Ericsson is a global fabless company, a leader in supplying wireless platforms and semiconductors to the world's leading wireless device makers. This company is supported by extensive semiconductor manufacturing experience and telecom heritage. Around the world more than 85% of employees are devoted to research and development. One in four mobile phones sold in 2011 was powered by ST-Ericsson. This is because the company continues to set the standard for innovative architecture, hardware and system integration. The company is backed by the strongest Intellectual Property Rights (IPR) portfolio in the wireless industry through its parent companies – Ericsson and STMicroelectronics. ST-Ericsson is headquartered in Geneva, Switzerland with main centers in France, Sweden, China, Japan, Korea and 20 more countries worldwide.

History

In 1987 SGS-Thomson was formed by the merge of SGS Microelecttronica, which was originated in 1972 from a previous merge of ATES (Aquila Tubi e Semiconducttori), Societa Generale Semiconduttori, both from Italy, and Thomson Semiconducteurs which was created in 1982 by the French government. During this merge and creation SGS-Thomson was ranked 14th among the top semiconductor suppliers.

Fig. i.i.i. 1 SGS Thompson Logo

In May 1998 Thomson SA withdrew as the owner and changed the name to STMicroelectronics.

Fig. i.i.i. 2 STMicroelectronics Logo

By 2005 STMicroelectronics was ranked fifth among worldwide chip makers after Intel, Samsung, TI and Toshiba. Actually STMicroelectronics is Europe's largest semiconductor chip maker.

In August of 2008 STMicroelectronics and NXP, formerly known as Philips, created a new joint venture for their mobile activities.

Fig. i.i.i. 3 NXP Logo

Finally on February 10, 2009, ST-NXP Wireless and Ericsson Mobile Platforms established the joint venture ST-Ericsson.

Fig. i.i.i. 4 ST-Ericsson Logo

Activity

ST-Ericsson is a leading global designer, developer, and fabless creator of platforms and semiconductors for wireless devices, and has been at the forefront of the development of multi-core processor platforms. More than *five million* phones have been built using ST-Ericsson's products and technologies and more than *one million* phones have been built on the company's complete platform solutions.

ST-Ericsson is unique in its ability to deliver state-of-the-art platforms, integrating mobile multimedia and connectivity for GSM, EDGE, WCDMA, HSPA, HSPA+, as well as TD-SCDMA and LTE. The company's platforms support major smartphone operating systems including Android and Windows Mobile.

Their professional relationships expand more than 15 years with the top phone manufacturers, which made it the leading supplier to four of the five top handset makers who represent around 80% of the entire handset market. ST-Ericsson is the leader in wireless access technologies, as well as a leader in convergence for mobile multimedia such as: platform architecture and integration, optimized power & size, full web experience and HD multimedia. ST-Ericsson also has an extensive involvement in standardization bodies, driving the development of new technologies.

ST-Ericsson is a fabless company supported by extensive semiconductor manufacturing experience and that ensure reliable delivery to their customers. The company has also the privilege of relationships with leading edge independent foundries and back-end suppliers as well as access to ST's world-class facilities.

ST-Ericsson develops and tests their reference designs thoroughly, while running the most extensive Interoperability Test Program (IOT) in the industry.

In order to stay competitive, ST-Ericsson constantly meets and exceeds the needs of their customers by offering a complete package of products and services.

Fig. i.i.ii. 1 ST-Ericsson Activities

Ecosystem

Ecosystems in mobile phones are changing because of the great added value of portability. This is the main reason why smartphones are becoming more independent and more necessary. Modems and connectivity are moving out of being only in the mobile phone market only and are entering new types of devices and services. Customer needs are pushing the manufacturers to bring mobility everywhere. One of the main requirements is to be enabled by the availability of technologies, at low cost, in packaged solutions. Mobile broadband is becoming a key enabler for growth; this is where ST-Ericsson comes in.

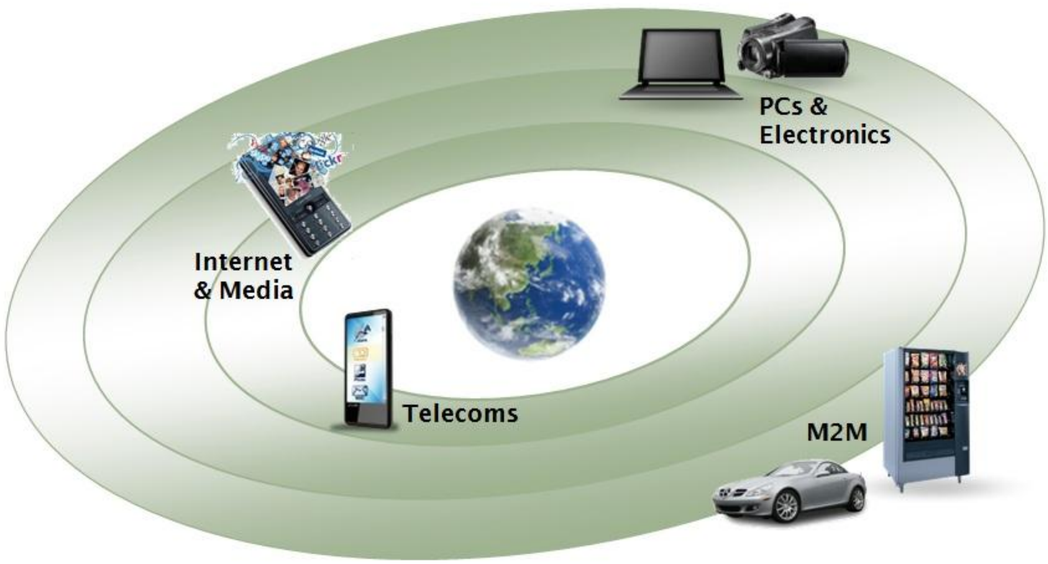


Fig. i.i.iii. 1 Semiconductor Ecosystems

As new ecosystems go mobile, they also start to enter each others territory

- This means new competition
- This means we need to understand these new ecosystems
- This means there are opportunities to expand, to partner Inter-Operator Tariff (IOT), to create new services to broader audiences, and to innovate.

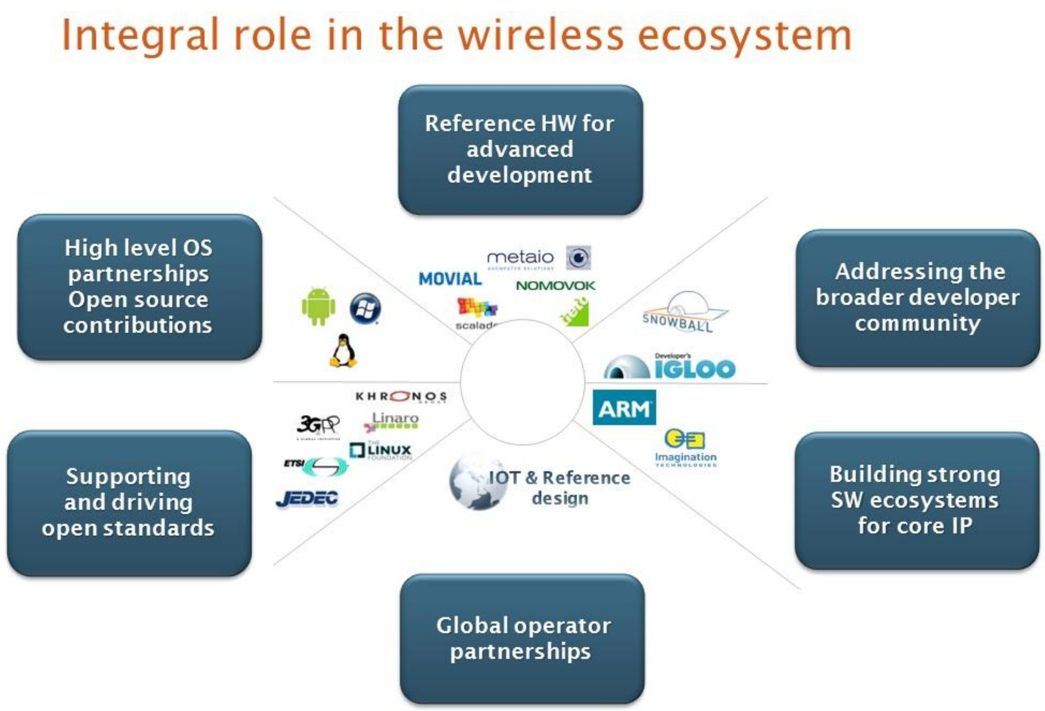


Fig. i.i.iii. 2 Integral Role of Wireless Ecosystem

According to Gartner (July 2009), by 2013 approximately six billions mobile service connections (subscriptions) will exist.

Partners / Competitors / Customers

ST-Ericsson thrives on collaboration to partner with the industry key players. The company has standing relationships with mobile phone manufacturers around the world spanning more than 15 years. Over four million phones have been built on ST-Ericsson products and technology. As an experienced partner, ST-Ericsson provides reliable support at every stage of product development

Some of ST-Ericsson software partners are:

Asmaitha

Azurewave

Calao

Linaro

Metaio

Movea

Movial

Myriad

Noalia

SRS

Tieto

Fig. i.i.iii.i. 1 ST-Ericsson Software Partners

Between the top semiconductor industries there exist some well-known companies such as QUALCOMM, Texas Instruments, Intel, Samsung or Infineon. Who are the direct competitors for STMicroelectronics and ST-Ericsson. STMicroelectronics was ranked 5th in semiconductors industries in 2011.

ST-Ericsson leads the way forward with new access technologies, connectivity and multimedia capabilities, while also improves continually existing technologies and solution, shortening time to market and reducing total cost.

ST-Ericsson creates a demand for greater standardization. ST-Ericsson is actively involved in standardization bodies within the industry securing innovation that benefits the entire industry.

ST-Ericsson offers a complete portfolio of wireless platforms for all market segments. Even though is consider a fabless semiconductor company, its wafer processing is performed by STMicroelectronics facilities and external foundries. The platform offers, with solutions integrating mobile multimedia and connectivity for GSM, EDGE, WCDMA, HSPA, as well as TD-SCDMA and LTE. Multimedia and application processors are compatible with all major operating systems, while connectivity and broadcast solutions for Bluetooth, FM, GPS, WLAN, Near Field Communications (NFC) and USB provide a greater mobile experience.

Lenovo LePhone S899t smartphone - designed for China Mobile in 2012 - is powered by the ST-Ericsson Nova™ A9500 application processor. This is the first smartphone from Lenovo which is built on ST-Ericsson dual-core high-performance application processor. In addition to the Nova A9500, ST-Ericsson CG2900 and CW1100 connectivity solutions were also selected by Lenovo enabling GPS, Bluetooth, FM and Wi-Fi features.

ANT Wireless, a division of Dynastream Innovations Inc., announced the newest addition to its ANT family of silicon solutions: the ST-Ericsson CG2905 GNSS/Bluetooth/FM single chip device.

ST-Ericsson continues to expand cooperation with Chinese manufacturers on NovaThor U8500 and its upgraded version the NovaThor U8520.

Fig. i.i.iii.i. 2 NovaThor U8500 Devices

ST-Ericsson's biggest customers are between: Huawei, Nokia, Research in Motion, Sony, Ericsson, HTC and Samsung.

Fig. i.i.iii.i. 3 ST-Ericsson Customers and Products

Company organization overview

ST-Ericsson is headquartered in Geneva, Switzerland with main centers in France, Switzerland, Sweden, Finland, Germany, UK, India, Singapore, China, Japan and Korea and 20 more countries worldwide. Proving ST-Ericsson is truly a global company, with more than 6700 highly skilled engineers.

Fig. i.ii. 1 ST-Ericsson Company Organization

Fig. i.ii. 2 ST-Ericsson Global Presence

My service – role

Under the direction of Raphael Tabardel, an engineer with over 30 years of service in STMicroelectronics and ST-Ericsson, the BDB Team is in charge of performing software and hardware tests to new mobile devices such as smartphones and tablets. These tests will measure the performance of components and platforms from ST-Ericsson and especially from the competitors. While measuring different types of phones and components we are able to create an internal database ran and controlled by two teams placed in different ST-Ericsson bases.

The first is the Support Team with over 4 engineers based in Sophia Antipolis which controls all the access and interaction between users and developers, is also in charge of data transmission and monthly news.

The second team is the Analysis Team based in Grenoble, France. Five workers are in charge of analyzing each new device and running all the software and hardware tests to obtain all relevant information that will be submitted to the database and that will be sent to specific departments that may be interested in specific components. Some of the software tests are focus on: Graphics, CPU, Connectivity, Browser, Memory and Java.

By creating an algorithm in computing software we are able to analyze the power consumption of any given device while performing different actions like taking pictures, listening music, downloading a file, etc.

In the hardware point of view we focus on analyzing: Digital Base band (DBB), Memory, RF2G, RF3G, PA 2G, PA 3G, Power Management Unit (PMU), WLAN, Audio codec and GPS packages. RF stands for the Radio frequency *Transceiver* and PA for Power amplifier.

All these processes will be fully explained along this document.

Strategic Planning Group

During 2010 – 2011 ST-Ericsson's Strategic Planning Group was in charge of Edgar Auslander (one of the founders of Texas Instruments Wireless Business Unit).

The group objective was to:

- Analyze the situation of ST-Ericsson in the market.
- Define goals and objectives.
- Finally set or propose the paths and Roadmaps to be achieved.

The Strategic Planning Group is based in Sophia–Antipolis, France and controls the Grenoble, France base.

Benchmarking and Competition survey

In ST-Ericsson's intranet, a database tool was created over 8 years ago. It started as a simple feature to search studies. Over the years it has been adapted to new requirements in order to maintain its functionality and priority. This tool actually is used by more than 3200 ST-Ericsson employees and over 2000 STMicroelectronics associates; the actual name is Benchmarking Database or simply BDB. From the beginning, the BDB has evolved as a more sophisticated and organized tool. It contains information related to the mobile device such as description, features, characteristics and a picture of the device.

Fig. i.iv. 1 BDB Platform Display 1

A complete list of components including the function, manufacturer, type of package, picture, dimensions, number of pins, datasheet, estimated price, etc. is displayed for each device.

Function	Comp
DBB + RF2G + RF3G	QSC6(
PMU	TWL3(
PA2G	TQM6:
Memory Combo	JZ58F
Memory Combo	TY900
WLAN + BT + FM Receiver	WL12:
AE	OMAP
WLAN FEM + BT RF	6792
GPS LNA	uPC82
Audio CODEC/DAC/Amp	TLV34
USB transceiver	MAX3-

Fig. i.iv. 2 BDB Platform Display 2

Links for downloading any document related to the phone, like the user manual, press release, studies, etc, are available either from the internet or confidential source.

Reports [Add Report] | [History Log]

Type	Company	Short Title	Downloads/Links
Benchmarking report	ST-Ericsson	N6788 multimedia	Pictures 2592 x 1944 (2.48 MB) Videos MP4 (16.79 MB)
Data file	Nokia	N6788 CD content	CD content (61.7 MB)
Datasheet	Nokia	N6788 datasheet	Fact sheet (915.85 KB)
Press Release	Nokia	Nokia launches its first TD-SCDMA device - the Nokia 6788	Link to the original source
Product Brief	Nokia	Nokia 6788 device details	Device Details (44.89 KB)
User Manual	Nokia	N6788 User Guide	User guide (English) (758.61 KB)

Fig. i.iv. 3 BDB Platform Display 3

All this information is used to compare or analyze competition packages mainly with ST-Ericsson solutions. Competition analysis is vital to understanding costumer needs and offering a better solution and reducing costs by reducing package dimension.

Fig. i.iv. 4 Teardown Example

Chapter 1 - DEVICE OVERVIEW AND COMPETITION APPROACH

Mobile devices (Introduction, overview and state-of-the-art)

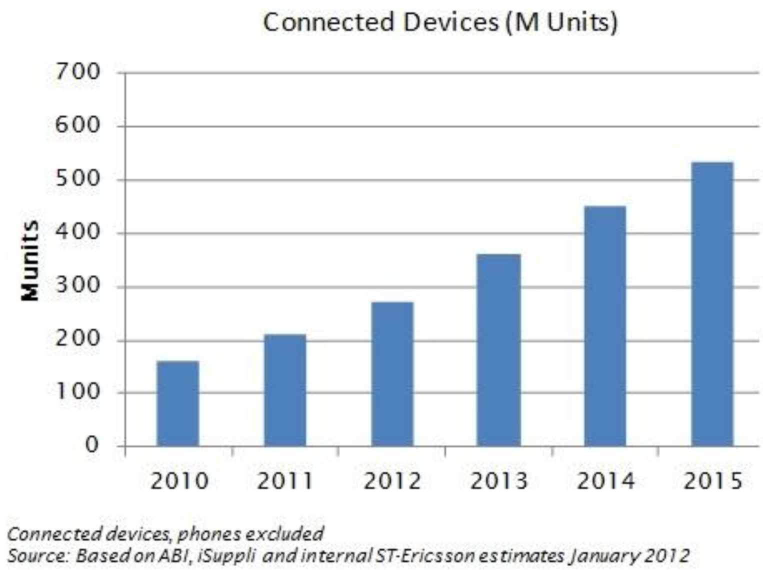
Mobile device comes from the Latin *mobilis* that means “to move”. A mobile device is commonly known as a handheld device, handheld computer, or simply a handheld. A handheld is a small computing device which has a touch or non-touch display screen and/or a mini keyboard.

Between the most common mobile devices are the mobile computers, mobile phones, and others like Cameras or PDAs (Personal Digital Assistant). Like a computer, a mobile device requires a *Mobile OS (Operational System,)* or a platform to run all the programs or applications.

First examples of revolutionary mobile devices can be found in the electronic calculator that was released in pocket size in 1970, the electronic camera invented in Eastman Kodak in 1975, Microvision 1979, and “*Watch&Play”* from Nintendo in 1980, among others.

Fig. 0.1 First compact 100% electronic calculator (www.kirianet.com)

Internet connectivity has been a major change in mobile devices from the beginning.



Smartphones

The term “Smartphone” was first introduced by the company Ericsson when they gave this appeal to their GS 88 “Penelope” in 1973. The first actual smartphone ever produced was the “SIMON Personal Communicator” made by International Business Machines Corporation, more commonly known as IBM, in 1992. This smartphone was produced from 1994 to 1995 and it included a calendar, phone book, emailing availability, calculator, notepad, alarm clock and a multi-touch screen which was first invented in 1984 by Bob Boie at Bell Labs.

A smartphone has developed its characteristics and functions over the passing of years. It started with the pairing of a PDA with a mobile phone, and with basic availability to read emails and surf the web on a monochromatic screen. This evolved into color screens (Nokia 9120 Communicator), smartphones with cameras (brought on by the joint venture between Sony and Ericsson in the SONY Ericsson P800), the integration of Operational Systems such as Windows Mobile in a phone for the first time (T-mobile Pocket PC Phone Edition), Infrared Technology (Nokia 8310), Bluetooth Technology (Ericsson T36) and other improvements such as high definition cameras, high performance mobile connectivity, high performance mobile processors, large high quality touch screens, Open OS and an applications ecosystem.

Fig. 0.2 Mobile phone evolution (newcomtechblog.wordpress.com)

Smartphone growth has increased every year and will continue to according to user's needs.

A 2011 study shows that 63% of smartphone users connect to the internet every day, and 95% percent of those users want access everywhere. The smartphone user behavior puts great demands on battery life, network capacity and coverage.

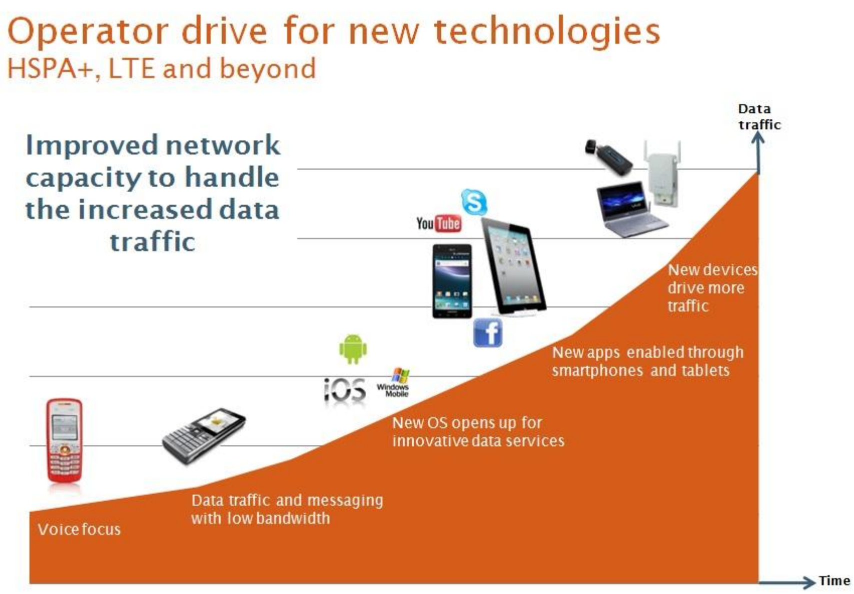
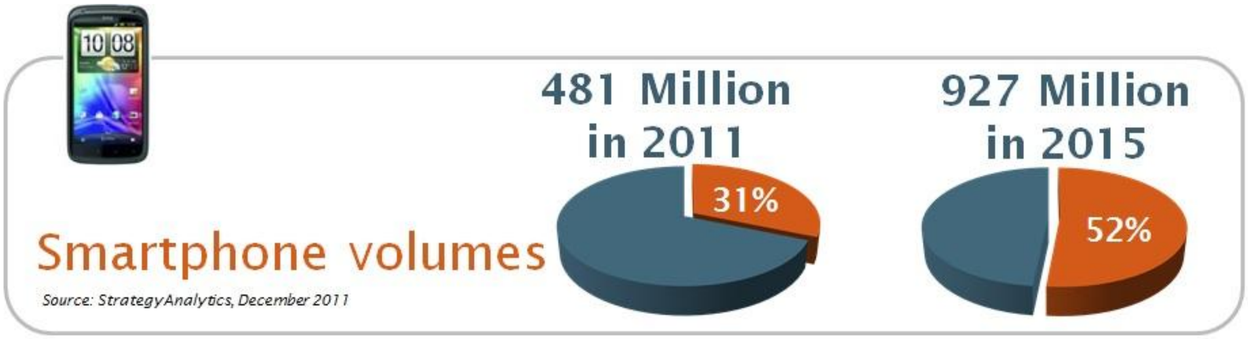


Fig. 0.3 Data traffic VS. Time (STEricsson)

The number of smartphone devices in the market has increased substantially in the last couple of years and is expected that by 2015 smartphone production will exceed the production of the rest of handsets.



Tablets

Tablet history does not go back as far as smartphone history. It became a trend during 2010 when Apple computers released the first Generation "iPad". The attempt to give similar characteristics of a computer in a small device had finally gotten a real approach.

During the last two decades scientists have tried producing smaller computers that will give features similar to a laptop but compromised into a handheld device. Unfortunately the size of such devices was never small enough. Finally in the 1990's the objective took another approach which lead to increasing features of a smartphone device that concludes finally in the new generation of handheld devices called "Tablets".

There were several attempts to produce such devices before they got real world impact in 2010.

It all started as "Pen Computing" which used a Pen-like tool that is called "stylus". The main characteristic of this stylus was to give precision to the new touchscreen devices. Back at the beginning of the 1990's the gesture and handwritten recognition was at the very first steps. Between the most relevant prototypes and manufactured tablets are: Pencept - PenPad, Grid Systems Co. "Samsung" - GridPad and CIC Handwritter (1989), AT&T - EO Personal Comunicator (1991), Apple – Newton

(1993), Palm Inc. – PalmPilot (1996), Intel – Intel Web Tablet (1999), Microsoft – PocketPC (2000) and Nokia – Nokia770 (2005).

After almost a decade tablets have developed a new field of science in computers starting with simple recognition algorithms to state-of-the-art technology in terms of processors, memories, DBB, Transceivers, Amplifiers, wireless connectivity among others.

Mobile Broadband modems

Mobile Broadband Modems have a variety of names like wireless modem, personal hotspot, data card, connect card or dongle (Europe). Its function is to connect to the internet or to another mobile device through a mobile broadband connection.
The wireless technology is one the most important changes in mobile devices. It marked the beginning of the new era in communications. Wireless systems will set a before and after in human mankind.
Wireless technologies are divided into 4 categories based on their reach.

- Personal Area Network (10 meters)
  - Bluetooth (802.15)
  - Ultra Wide Band - UWB (>500MHz)
- Local Area Network (50-100m)
  - WLAN (802.11)
- Wide Area Networking (Few Kms)
  - WiMAX (802.16)

- WCDMA
- HSDPA

- Broadcast (10Km and above)
  - DVB
  - DAB
  - MBMS

The wireless technology and wireless access to internet will enroll in a race to provide efficient mobility versus data rate acceptance. In other words, companies are trying to provide the largest coverage, with the fastest speed, in a reliable standard. This forced different groups of telecommunications associations to collaborate between themselves. Starting from the 1G which had an analog signal, standards had evolution to increase the data rate over the mobility.

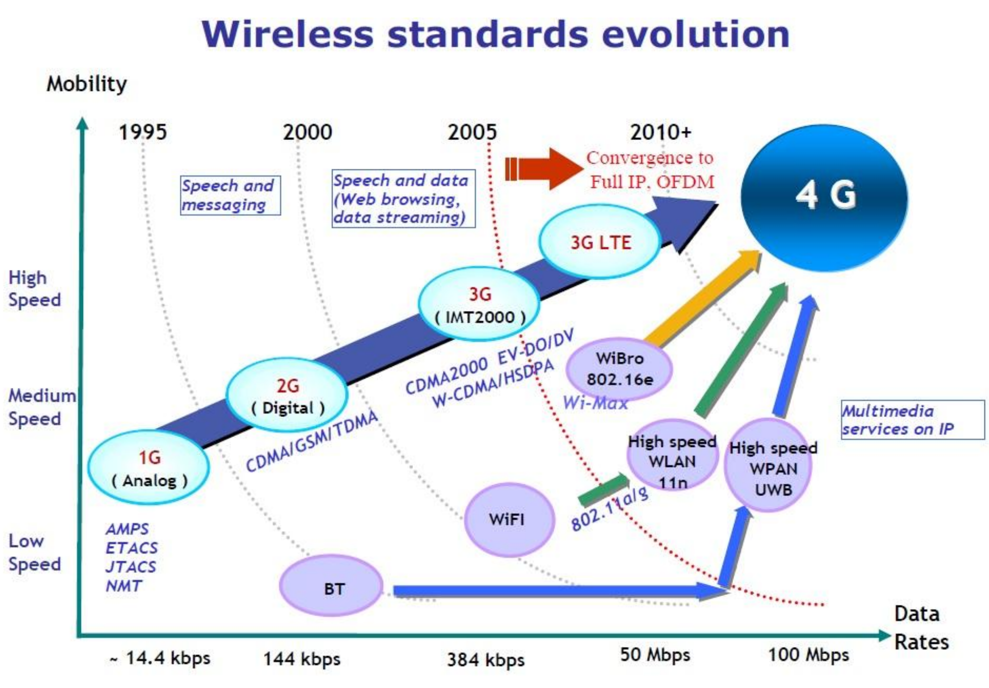


Fig. 0.4 Wireless standards evolution (STMicroelectronics)

This study is focused in GSM Standard that was originally created as a replacement of the analog first generation cellular networks. In the world, under the 3GPP Family, the most popular standard for mobile phones is GSM (2.2 Billion users). The mobility data service for this standard was GPRS which later evolved in EDGE, W-CDMA (UMTS), +HSPA and finally LTE.

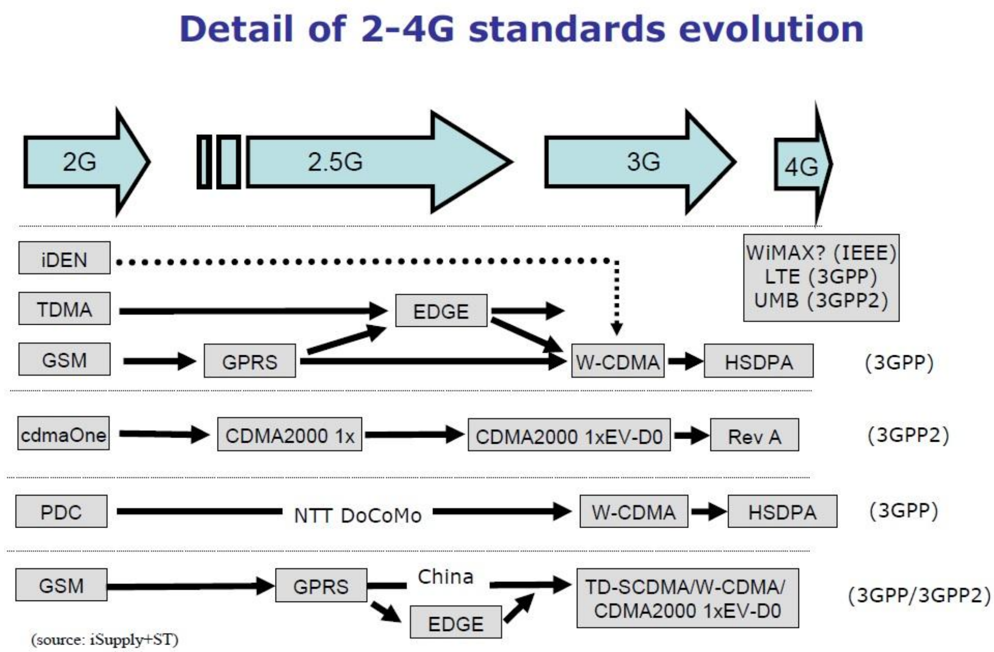


Fig. 0.5 Evolution of 2G to 4G (STMicroelectronics and iSupply)

Smartphone perspective

Smartphone evolution had become a larger market every year for developers to obtain a closer approach to users needs. During the last decade smartphones have helped solve users difficult situations, and were seen as an important tool, but nowdays smartphones have become an indispensable machine for the everyday living. Innovation is the key feature of a smartphone.

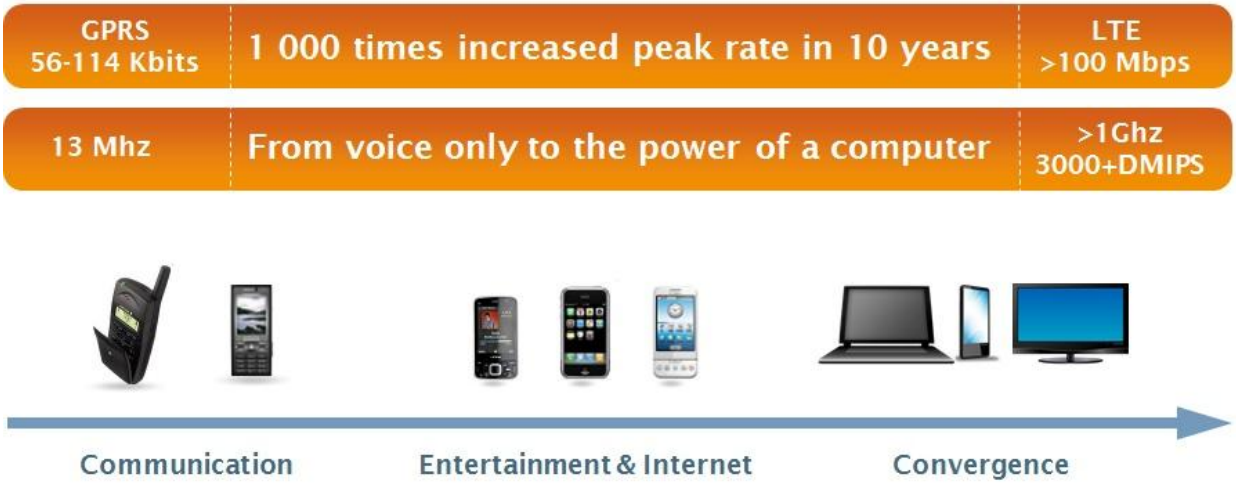


Fig. 0.6 Speed and Processor evolution (STEricsson)

Professional VS Public interests

As in any other field of electronic users, smartphones are targeted to different economic classes and type of users. An important factor to develop a smartphone is to be aiming towards the right target.

Smartphones are targeted principally to two main sectors: professional and public. This does not mean that these parameters are exclusively ones from others. Simply the two main sectors have preferences.

For the professionals, smartphones are part of their work. They are a tool that helps to complete their work and to make sure it is correct. They rely on smartphones to make big desicions at the right time. Key aspects and features to look for in a professional point of view are:

- Network, being able to stay connected and not lose signal due to the smartphone components.
- Speed, usually in business time could be the difference between a big win or lose.
- Professionals seek for OS and Apps friendly smartphones with a wide support.
- Information management, meanning being able to view, organize and most of the times edit information. Also to be synchronized with agenda, calendar, alarms, etc.
- Security is an important factor for professional usage smartphones.

While the public user is focused on several different interests, such as the aspect and design of the smartphone, usually taking into consideration size and weight. Cameras, LED flash and screen resolutions are very important for general public with the tendency for bigger and more clear screens and cameras with better resolutions. Larger capacity memories are often more important for the general public than from professionals. Entertainment such as Audio, Music, Video, Games and social media interaction are probably the most important feature general public are looking for in a smartphone as well as price.

Market interest vs. Technical topics

The market has also tried to develop a more efficient duration of battery, this being probably one of the bigger problems developers have run with. This interest is a common between all types of users of smartphones. Trying to do smaller and more durable batteries has been the most difficult task in smartphones.

The data transmition and wireless internet access on mobile devices has made it possible for the users to connect the world instantaneously anywhere, being this is one of the pricipal demands of users. In the next diagram are some of the most important features of mobile service from a general point of view.

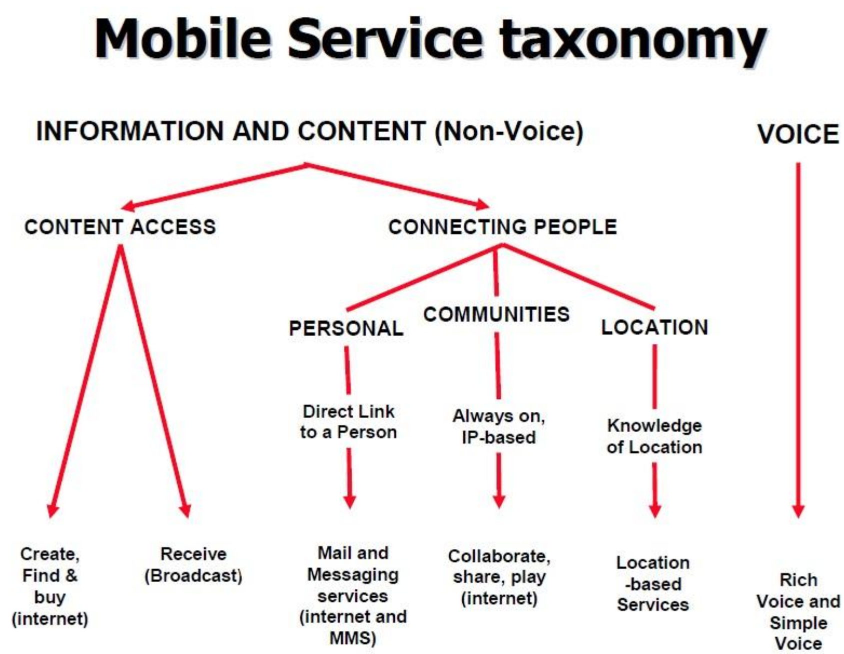


Fig. 0.7 Mobile service taxonomy (STMicroelectronics)

The technical topics that the industry is facing and will have to face for the next couple of years include: amazing user experiences and mobile computing power, leading performance and power consumption reduction, single chip integration (smaller devices), market ready solutions to users discomfort, social networks enhancing, cloud storage capabilities, augmented reality by improving processor / screen / AE, online multimedia enabled, high-definition content. Cameras will continue to play an important role (12 times more camera phones sold in 2011 than cameras). A-GPS development (GPS penetration doubled in the past 2 years) and 3D interface with new screen and cameras also with this feature. Mobile for the enviroment (becoming green). Emerging energies to replace Li-Ion batteries.

Proposals (Roadmaps)

In order to maintain expectations and reach goals, industries set their roadmaps regarding the technology to be used and integration in new devices.

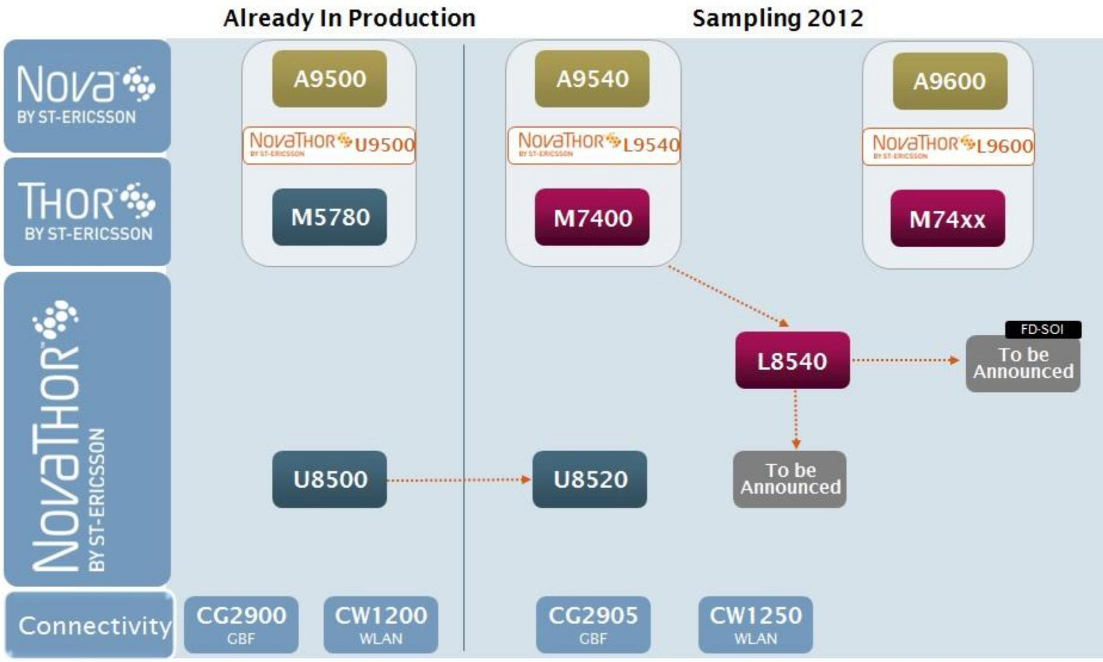


Fig. 0.8 NovaThor Roadmap (ST-Ericsson)

ST-Ericsson roadmap includes the all new Nova (Application Processor) and Thor (Mobile Broadband Modem). Combined, the result is a Complete platform to be introduced in new smartphones.

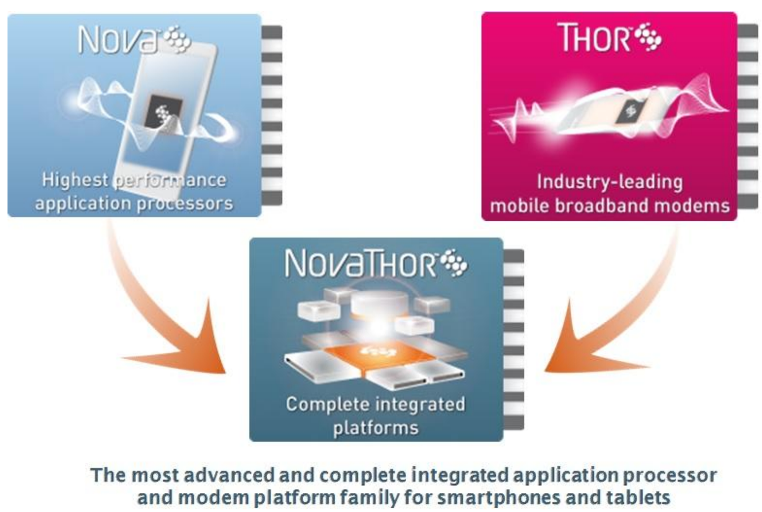


Fig. 0.9 Nova + Thor Family (ST-Ericsson)

ST-Ericsson Platform Portfolio Roadmap for different standards that are in production and that have been announced is shown in the graphic below.

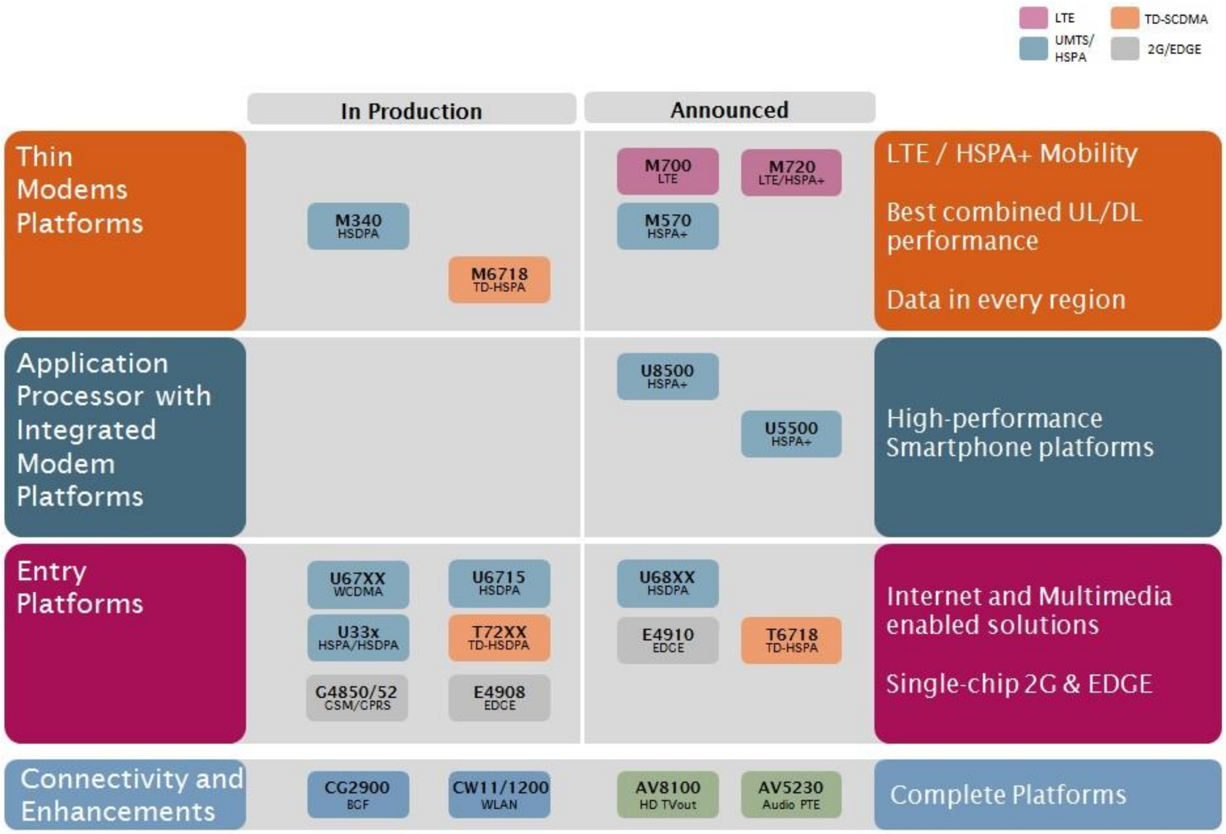


Fig. 0.10 ST-Ericsson Platform Roadmap (ST-Ericsson)

Component integration on mobile devices

Mobile devices are forced to have certain components in order to perform their most element and most complicated tasks. These components will affect the performance of the mobile device. Like seen in a car, all the components have to work together as only one. For example, no formula 1 race motor will perform correctly with a SUV chassis. The component integration is subject to many tests in prototype versions. Such versions will measure interaction and compatibility between components to obtain the best performance possible.

In this phase of the development of smartphones project designers try to obtain the new features promised, in the smallest space possible, with a perfect compatibility between component and manufacturers.

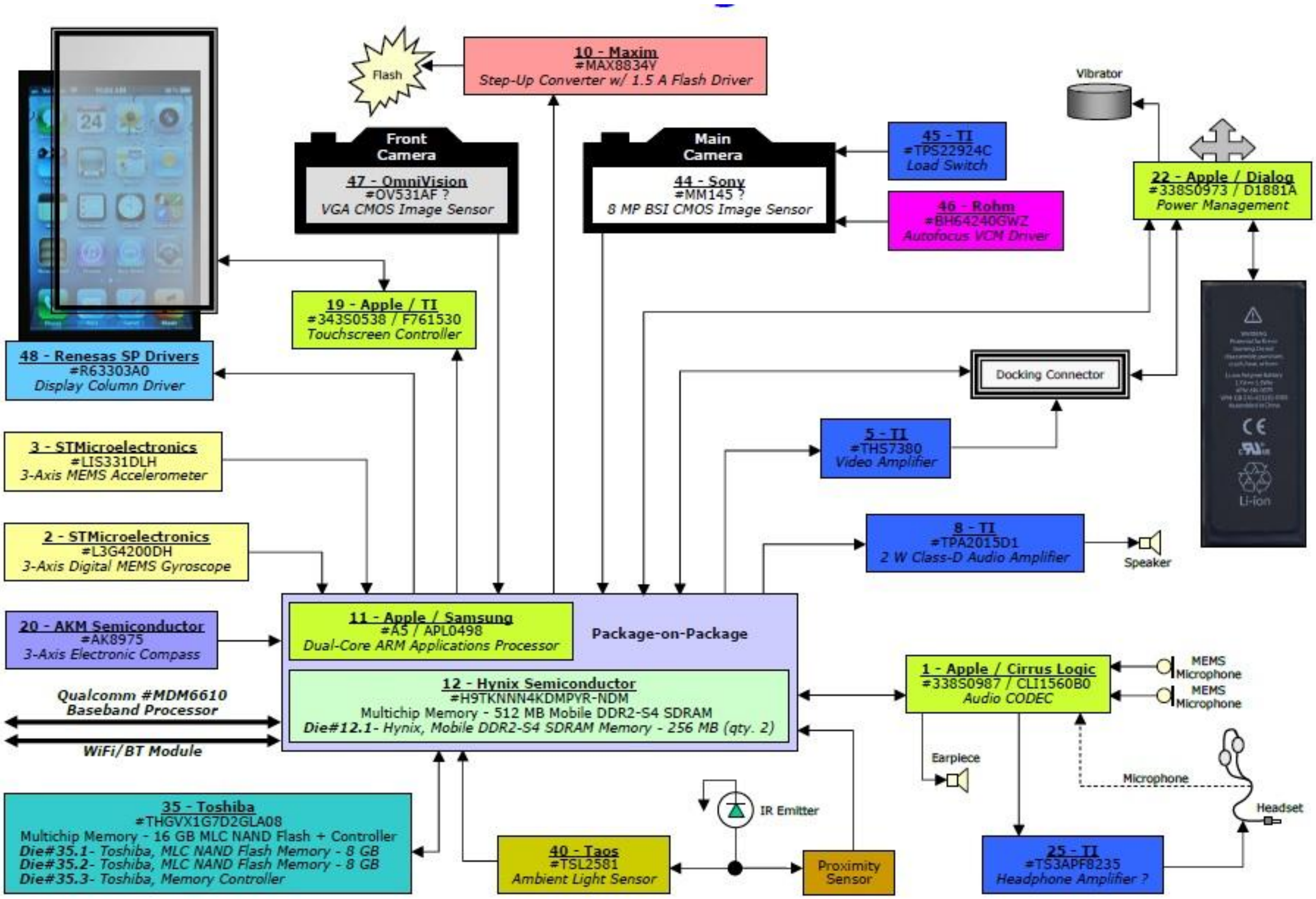


Fig. 0.11 iPhone 4S Block Diagram 1 of 2 (TechInsights)

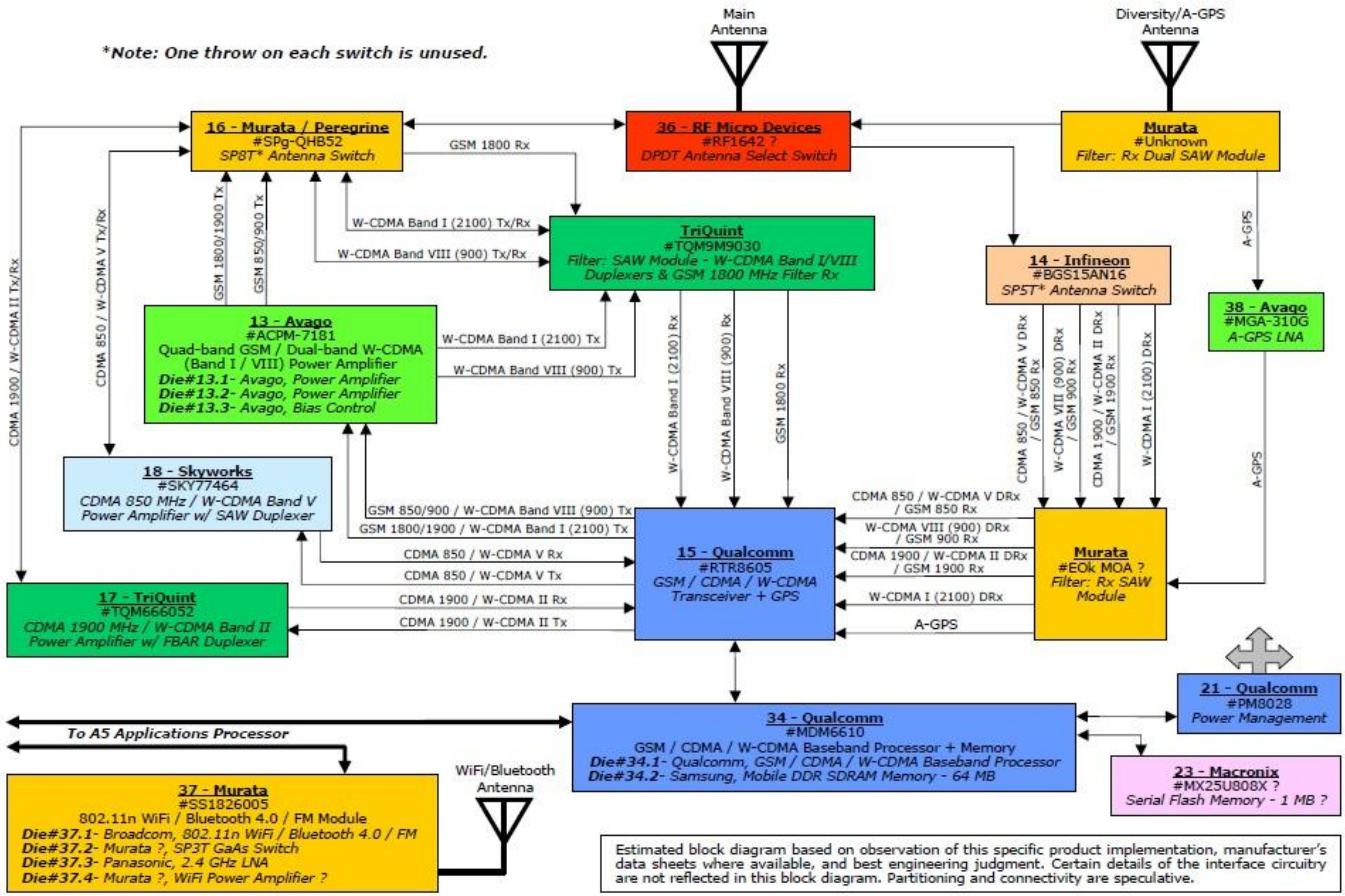


Fig. 0.12 iPhone 4S Block Diagram 2 of 2 (TechInsights)

Functional blocks

In every PCB board the physical distribution of the components will affect the interaction between them and the total space needed. These areas are limited according to the functions of each component. The following picture shows the functions of a certain area delimited by colors. Each area encapsulates a specific function of the device. These functions will be explained in section 1.3.1.1.

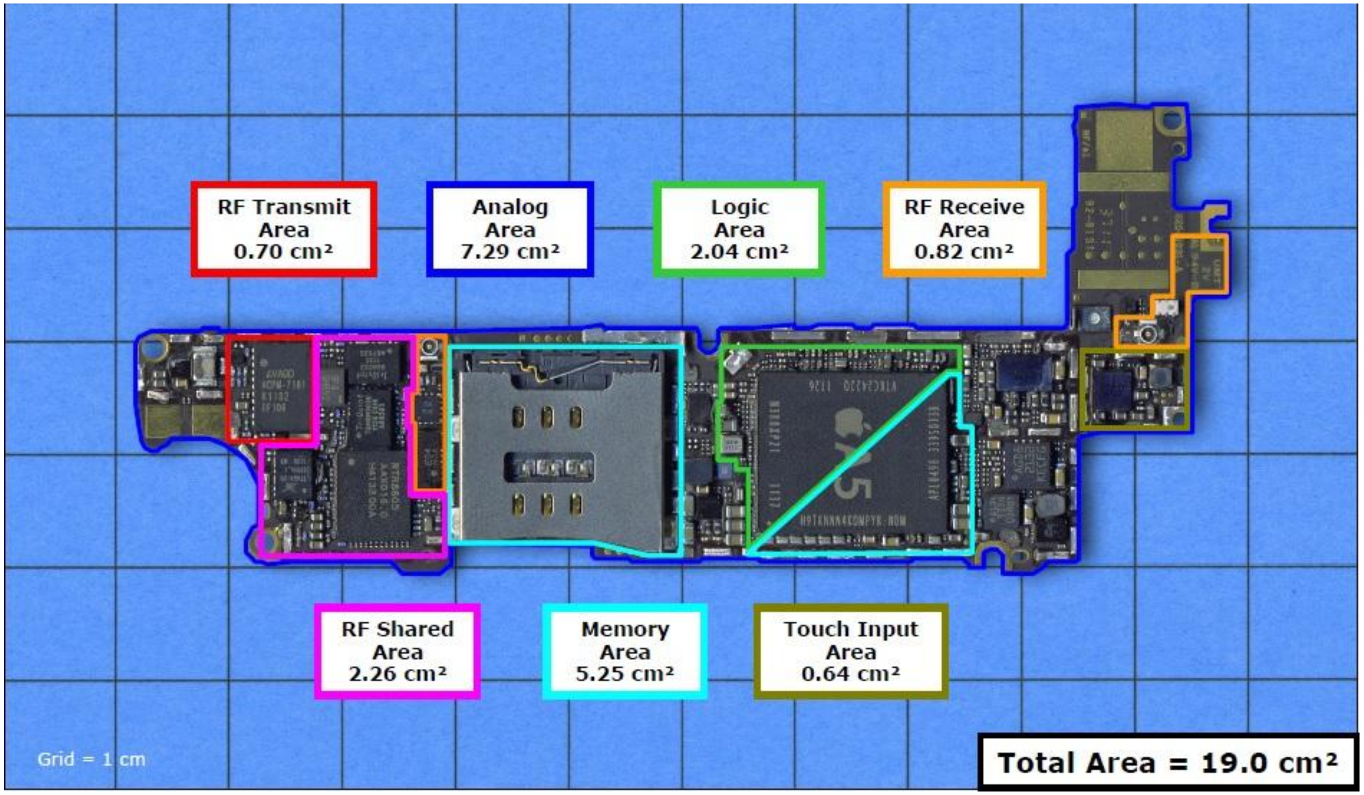


Fig. 0.13 iPhone 4S Main Board Side 1 Functional areas (TechInsights)

These areas can be in opposite sides of the PCB, but connected through it by different types of vias in between the PCB layers (explanation of PCB vias and layers in chapter 2.3).

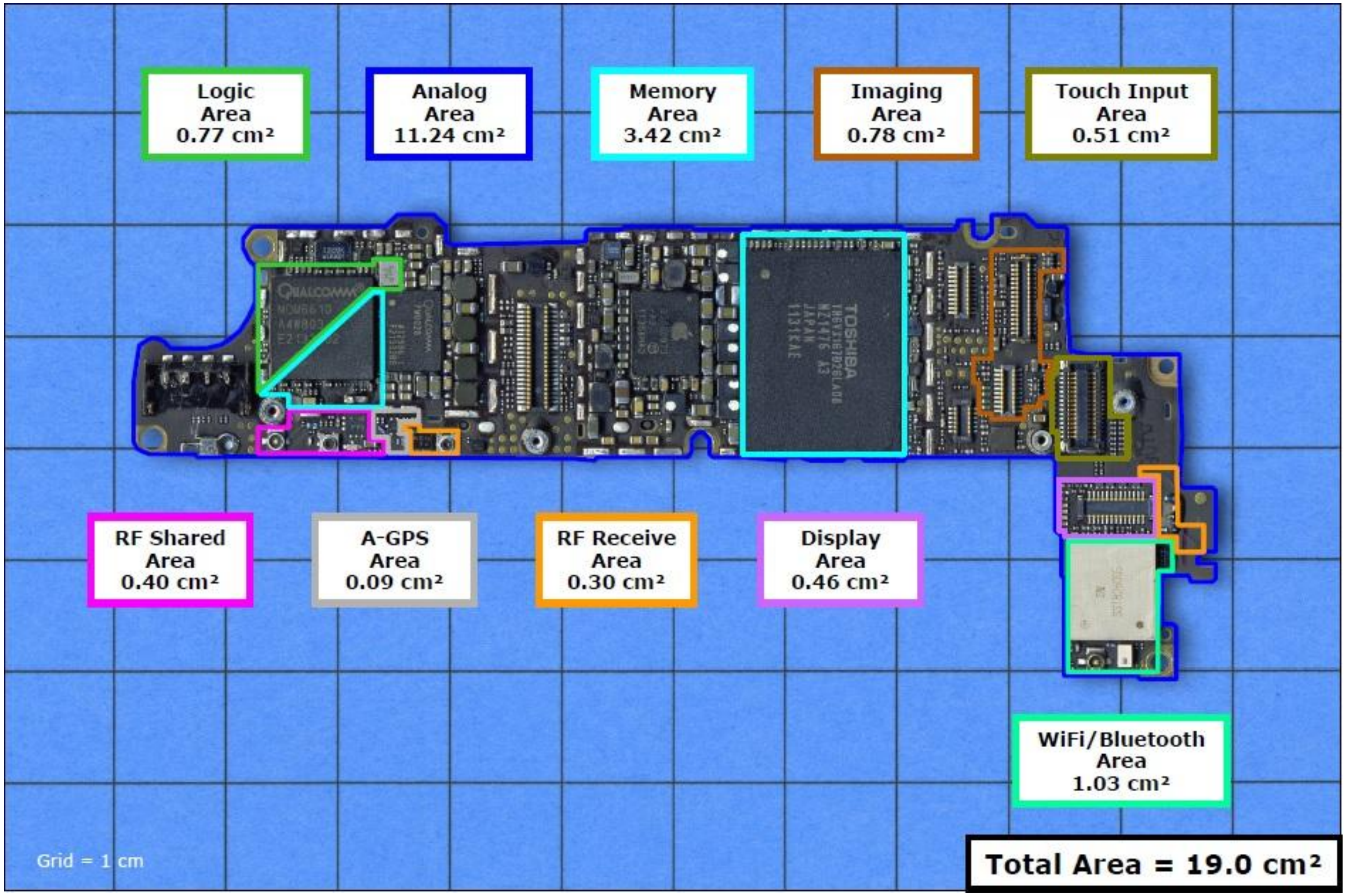


Fig. 0.14 iPhone 4S Main Board Side 2 Functional areas (TechInsights)

DBB / AE / PMU / RF / Connectivity

In the Logic area of a device is an indispensable DBB (Digital Baseband), which is the component that performs the signal processing. All radio transmission operations are also performed by the DBB. In other words, every component that is connected to an antenna will send the information to the DBB to be processed. Also in the logic area there has to be an "Application Engine" (AE) mostly known as "Application Processor" (AP). This component is designed to support and control all the applications running on a Mobile OS as well as graphic processing, multimedia decoding and memory management. Even though both of these SoC's are in the logic area they are independent from one another.

In the following block diagram there is the BCM21551 Baseband Processor which also includes an Audio processor.

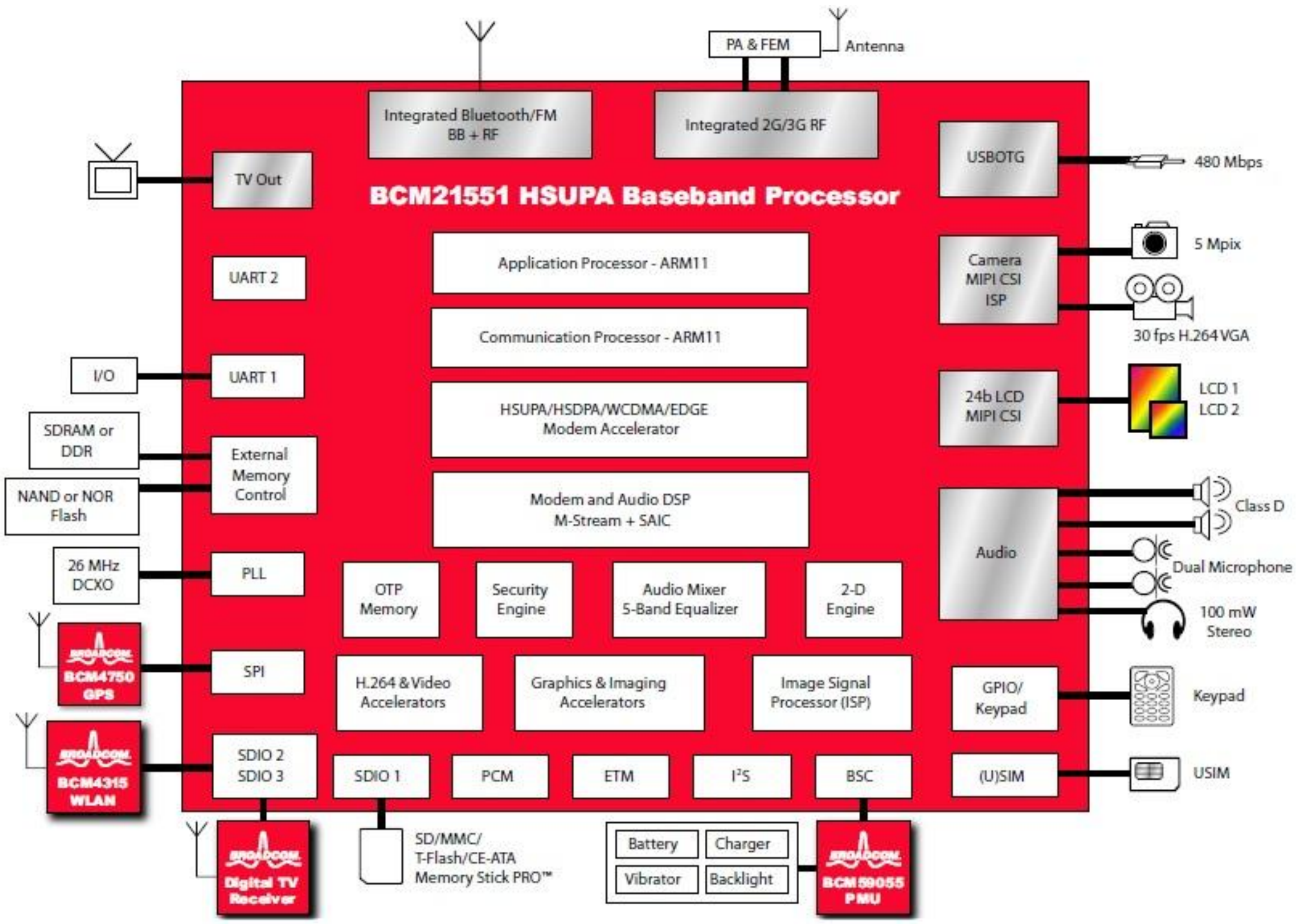


Fig. 0.15 Broadcom BCM21551 Block Diagram

In the Analog area of the PCB there are all the components that perform operations on an analog signal. In the analog area there are signal amplifiers, audio amplifiers, sensors, audio CODEC, DC-DC convertors, Power Management Unit (PMU), switch, regulator, speakers, microphone, vibrator, etc.
One of the most important is the PMU. This microcontroller is in charge of all the power functions of the platform. It controls almost every power consumption function in a mobile device. It runs diagnostics constantly to optimize user performance by the management of power consumption.

The basic function of a smartphone will always be the phone voice-capability. This capability can only be performed by the processing of the Radio Frequency (RF) signals. In this area there are components such as Power Amplifiers, Transceivers, antenna switch, duplexers and saw filters. All of these components, with the exception of the antenna switch, will depend on the type of band the smartphone is designed to work on. In the Apple iPhone 4S, for example, is a Quad-band GSM + EDGE; meaning that it works on W-CDMA frequencies 850 / 900 / 1900 / 2100 which corresponds to bands V / VIII / II / I respectively. This is reflected on the components listed below.

Manufacturer	Part Number	Package Description
Avago	ACPM-7181	Quad-band GSM / Dual-band W-CDMA (Band I / VIII) Power Amplifier
TriQuint	TQM666052	CDMA 1900 MHz / W-CDMA Band II Power Amplifier w/ FBAR Duplexer
Skyworks	SKY77464	CDMA 850 MHz / W-CDMA Band V Power Amplifier w/ SAW Duplexer
Murata	SAFFxxxxxxxxxxx ?	Filter: SAW - GSM 1800/1900 / W-CDMA Band I Tx
Murata	SAFFxxxxxxxxxxx ?	Filter: SAW - GSM 850/900 / W-CDMA Band VIII Tx
Murata	SAFFxxxxxxxxxxx ?	Filter: SAW - CDMA 850 MHz / W-CDMA Band V Tx
Murata	SAFFB1G88AA0F0A	Filter: SAW - CDMA 1900 MHz / W-CDMA Band II Tx

It is important to highlight that the most common manufacturer for SAW Filters is MURATA.

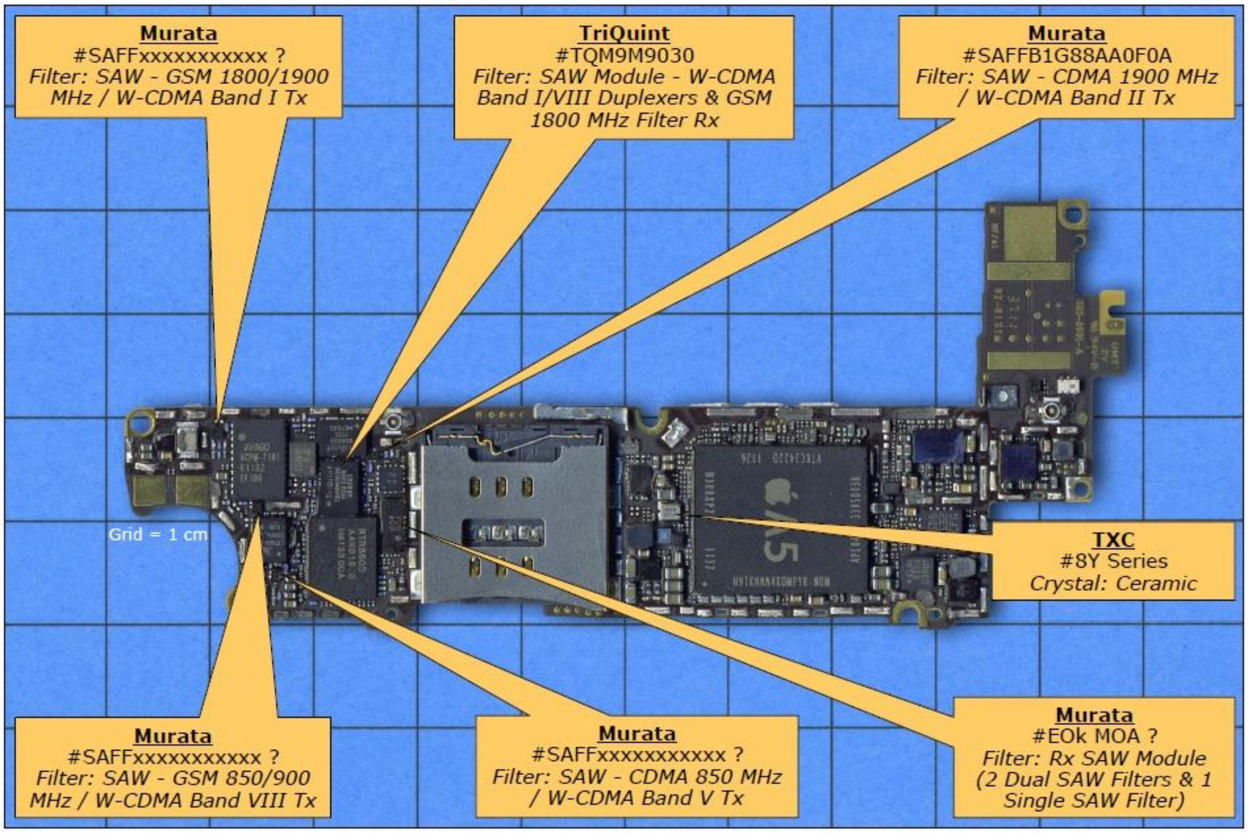


Fig. 0.16 Murata SAW Filters in iPhone 4S

For the connectivity area usually, but not always, in high-cost smartphones all the features including WiFi, BT, FM receiver (if capable) and GPS come all together in one single chipset. Bluetooth technology has been developing faster transmission rates in newer versions.

Specifications	BT 1.0	BT 1.2	BT 2.0+EDR	BT 2.1+EDR	BT 3.0 HS
Transmission Rate	721 kbits/s	721 kbits/s	2.1 Mbits/s	3 Mbits/s	24 Mbits/s
Adopted	2002	2003	2004	2007	2009
Backward compatible		yes	yes	yes	yes
Simple Secure Pairing		yes	yes	yes	yes

Standard Range			10 meters	10 meters	10 meters

(EDR = Enhanced Data Rate)

(HS = High Speed)

WiFi categories have increased as well as connectivity speed.

	Introduced	Freq. Band (GHZ)	Modulation	Maximum data rate
802.11	1997	2.4	DSSS/FHSS	2 Mbits/s
802.11a	1999	5	OFDM	54 Mbits/s
802.11b	1999	2.4	DSSS	11 Mbits/s
802.11g	2003	2.4 / 5	DSSS/OFDM	54 Mbits/s
802.11n	2009	5	MIMO - OFDM	600 Mbits/s

(DSSS = Direct-sequence speed spectrum)

(FHSS = Frequency-hopping speed spectrum)

(OFDM = Orthogonal frequency-division multiplexing)

(MIMO = Multiple-Input Multiple-Output)

For the Apple iPhone 4S, the connectivity module has various chips for what is called Multi-Chip Package MCP (for package types description refer to section 3.1) it simply means that various manufacturers accorded to develop a multi-function package by collaborating on its design. In this case the manufacturers were Broadcom, Murata and Panasonic.

Main competitors for ST-Ericsson

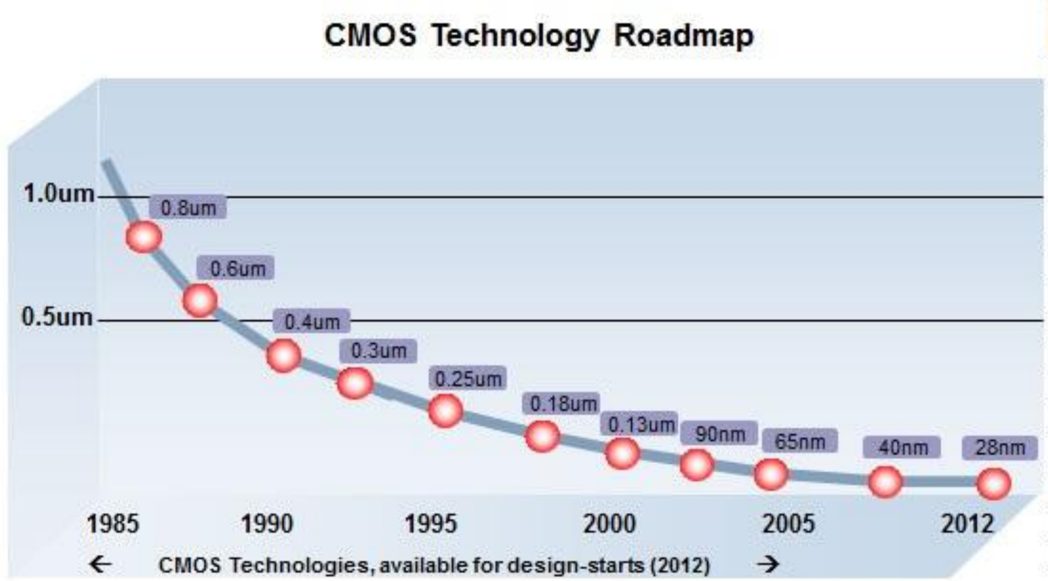
The semiconductor industry has developed stronger companies in different segments and areas. Murata has been referred to as one of the most reliable producers of Saw Filters. There are some strong companies producing state-of-the-art chipsets, modules, and components in specific fields like system platforms, application processors and RF transceivers. Mainly, production in the semiconductor industry has been led by some Semiconductor companies like: Intel, Qualcomm, Broadcom, Texas, Apple and Samsung. The next sections will be focused on these.

Other companies have their strong area like Hynix and Micron who produce NAND and SDRAM Memories, Toshiba and ON Semiconductors, who produce image sensors, Intel processors focused mainly on PC's market, Infineon in Connectivity or Mediatek, who develop processors especially for low-cost devices.

Complete system on chip (Platforms)

Also called SoC, these are integrated circuits (IC) that are basically differentiated from microcontrollers for their complexity. Usually a SoC is a MCP that contains a memory, either NAND or RAM, to be able to run software. A SoC will reduce space on designing a device by integrating various functions into one package.

To accomplish this integration process, technology has evolved during the years. This makes it possible to compress the chipsets more and more. CMOS stands for Complementary Metal Oxide Semiconductor. The CMOS Technology refers to the average half-pitch distance of a memory cell at this technology level. (Please refer to section 3.1.4 for half-pitch distance definition)



Semiconductor Manufacturing	
10 µm	1971
3 µm	1975
1.5 µm	1982
1 µm	1985
800 nm	1989
600 nm	1994
350 nm	1995
250 nm	1997
180 nm	1999
130 nm	2002
90 nm	2004
65 nm	2006
45 nm	2008
32 nm	2010
22 nm	2012
14 nm	est. 2014
10 nm	est. 2015
7 nm	est. 2017
5 nm	est. 2019

Fig. 0.17 CMOS Technology Roadmap (ST-Ericsson)

Qualcomm / Broadcom

Qualcomm is located in San Diego, CA. They are ST-Ericsson's main competitors in the processor development field whose main processor is the "Snapdragon" family processor. This processor family has a powerful CPU (Scorpion) usually between 0.8GHz and 1.2GHz and a GPU (from the Adreno family). It includes a multimedia sub-system, noise cancellation, echo cancellation and multiple screen resolution supports. Snapdragon CPU also incorporates a modem technology.

Fig. 0.18 Qualcomm QSD8250 Top-view picture

Broadcom is a fabless semiconductor company; this means that they don't produce their designs. Their main objective is to focus in their R&D (Research and Development) departments to develop new design and finally outsourcing the fabrication to other semiconductor companies called a semiconductor foundry. Broadcom is based in the USA and during the last 4 years have been placed between the top 10 semiconductor sales leader companies in the world with over $7200 million USD. Their processors are the BCM family and were introduced into the mobile market in 2012.

Fig. 0.19 BCM Processors (Broadcom)

Application engine (Graphic Accelerators)

NVIDIA / Texas / Apple

NVIDIA is an American based company that started with GPU dedicated manufacturing (GeForce). Founded in 1993 by three electrical engineers, it is now a referent in GPU development. Nvidia is now a SoC manufacturer as well. The "Tegra 3" GPU has a quad-core ARM Cortex A9 CPU and a GeForce GPU.

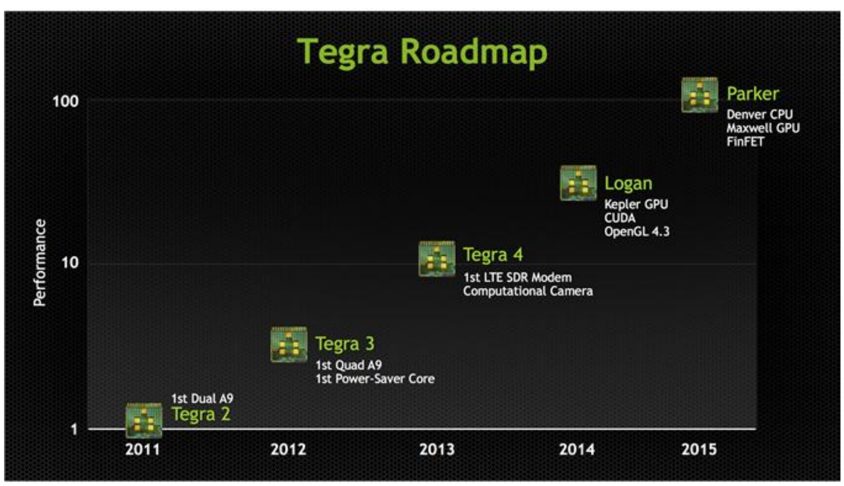


Fig. 0.20 Nvidia Tegra Roadmap (Nvidia)

Texas Instruments is also an American company that designs and manufactures semiconductors. The Open Multimedia Applications Platform or "OMAP" is the family of AP. Basically it consists of a high-performance AP produced in a 45nm technology process.

Also has a dual-core ARM Cortex A9 with frequencies between 1-1.2GHz to 1.3-1.5GHz depending on the model. For the GPU is a PowerVR SGX540.

Fig. 0.21 OMAP 4 Processor (TI)

Apple only designs their AP, they are manufactured by Samsung. Apple "A4/APL0498" Dual-Core ARM Application Processor has been produced in 45nm technology and is found in the iPhone 4S. Apple is considered by most to be the leader in SoC development.

Fig. 0.22 Apple A5 Processor (Apple)

Advanced LTE (RF Transceiver)

The LTE technology is a mobile solution. It will provider higher data rates. LTE will be effective in high–demanded urban areas boosting data capacity. The idea is that 3G will continue to provide data service outside these urban areas. Qualcomm has the first LTE/HSPA+/EV-DO multimode chipset. The launch of LTE could only be supported by them. Many operators announced their intentions to deploy LTE to raise data capacity on their 3G networks.

LTE could be expected to be launched in the second half of 2010. LTE Advanced should be the evolution of LTE. Infineon was the first company to present the first RF transceiver. The “SMARTi LTE” supports LTE capabilities single-chip RF transceiver.

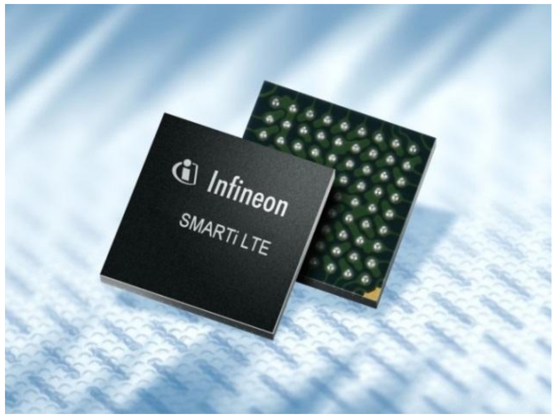


Fig. 0.23 Infineon SMARTi LTE Transceiver

Samsung

Samsung’s specialty had been memory production, but in 2010 they launched their first processor. In 2011 they launched the Exynos 4210 that is a 1.2 to 1.4 GHz dual-core ARM Cortex A9 SoC, produced in 45nm technology. It provides high-performance and power consumption efficiency and comes with an ARM GPU “Mali-400”.

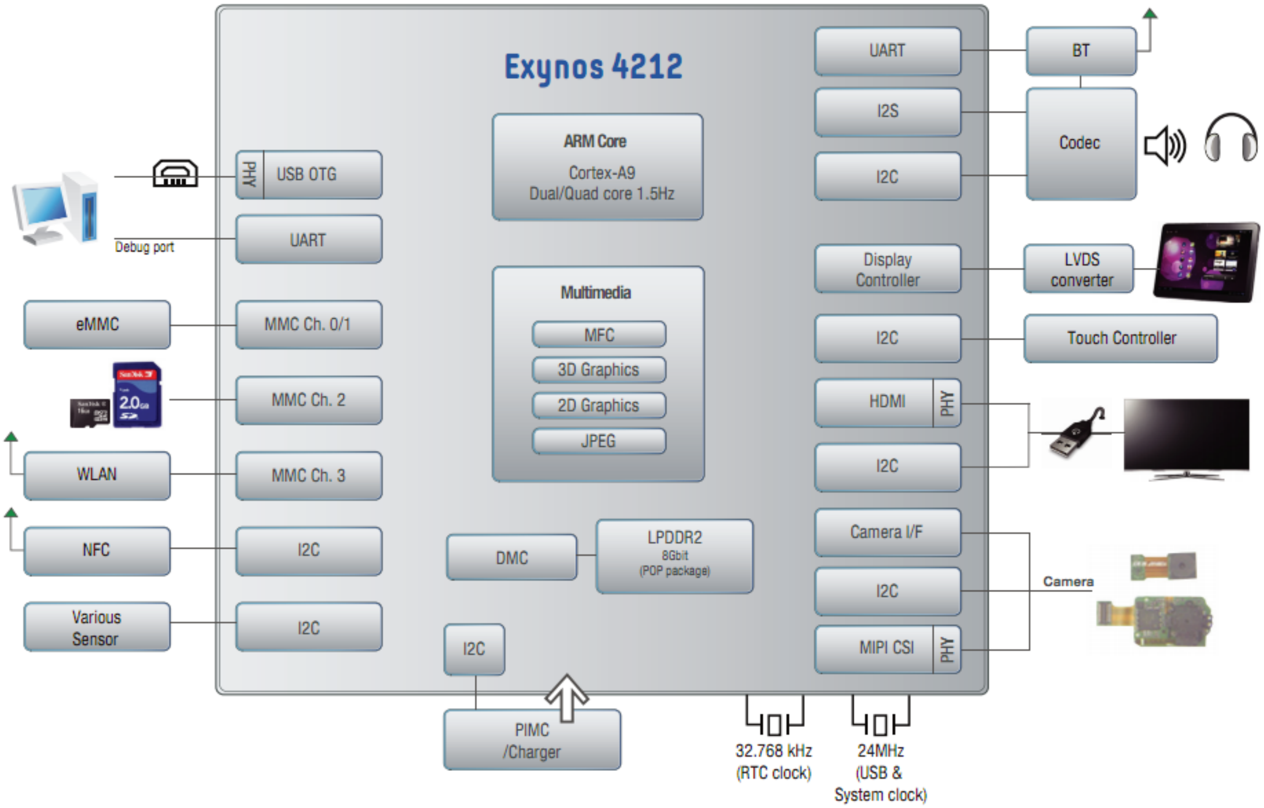


Fig. 0.24 Exynos 4212 Block Diagram (Samsung)

CHAPTER 2 - COMPETITION ANALYSIS

Approach

A competition analysis is based on ST-Ericsson's main competitors that were described in the previous section 1.4. STMicroelectronic's Grenoble Quality Team is the department responsible for the maintenance, calibration and improvement of the laboratories in the Grenoble Base. Grenoble laboratories are used by all the organizations based in Grenoble, to build and improve the quality of the products through fast and efficient reliability tests, failure analysis, debug support, and construction analysis. ST-Ericsson's BDB team uses such laboratories especially to accomplish the software and hardware analysis of mobile devices and its components. Some of these requests to the BDB Team come from various ST-Ericsson and STMicroelectronics. Quality at ST is directed by the Executive Total Quality Council (ETQC) and the Quality Steering Committee (QSC), both are in charge of the company quality strategy and to define/track key quality projects of the company.

Cost of manufacturing vs. Market Price

Smartphone developing industries search for the market's most reliable components that will position their devices ahead of their competition. Their goal is to increase customer satisfaction according to their needs and this satisfaction is based on key factors that were already explained in section 1.2.1.

To meet the new expectations on mobile devices, companies that produce smartphones, like ST-Ericsson, aim to produce more capable functions in the smallest chipsets, basically increasing the technology process (refer to section 1.4.1). For a new technology process to be produced the investment has to increase over the years. For example, to manufacture CMOS 32nm components, ST invested over $1.2billion USD in 2010. The return of this investment is larger in a considerable time if the product accomplishes its expectations. In section 2.3.1 Device Level, manufacturing cost is compared to retail market price of the device already in the market. Semiconductor companies strive for three key requirements smaller, faster and cheaper.

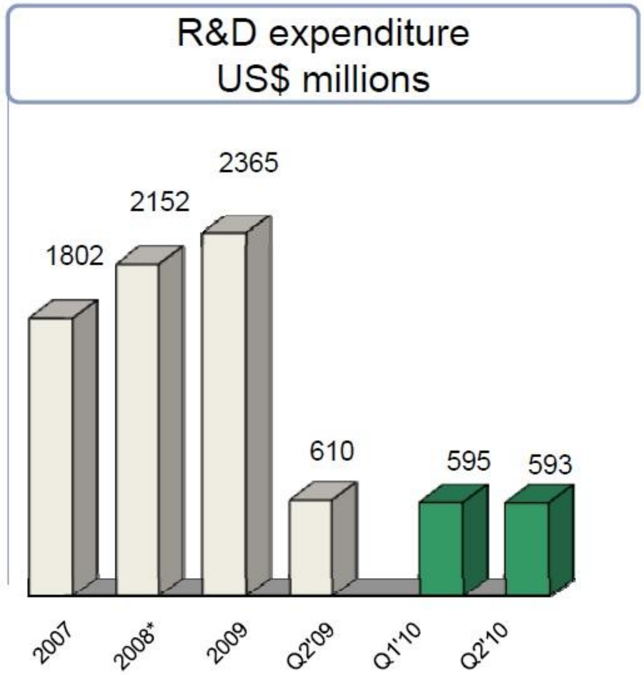


Fig. 0.1 Investment in Research and Development (STMicroelectronics)

In a simple explanation, smaller means finer lines meaning that more transistors can be packed on the same chip. With more transistors on a chipset, the faster it can do the work. This lowers the cost of manufacturing per chip and in a matter of months, the price of a new chip can fall 50%. The upgrade of mobile devices is so often that within a year customers eventually need to upgrade.

Performance analysis and Physical implementation

Performance analysis of a device is of major interest to manufacturers, network operators and mobile OS developers. This information is crucial when designing a new platform or chipset. It can help the industry optimize parameters to obtain a more powerful device. Key interests in this performance analysis are: Java, CPU, Graphics 2D/3D, memory, browser, connectivity, and user interface, among others (refer to section Performance Analysis 2.2.3).

The physical analysis is a study of new smartphones and tablets from a hardware point of view. The normal time to obtain a complete hardware study is approximately 33 working hours (almost a week) depending on the complexity of the device. Other devices, such as mobile modems or set-top boxes, are also studied but not as often and usually take the same amount of time. The devices are selected either by the BDB team manager for its importance to the company or by interest of special departments in the ST organization. A full report is later uploaded to the Benchmarking Data Base (BDB) and/or sent to the interested department who requested it (refer to section 2.3).

TIMETABLE FOR A DEVICE TEARDOWN			
	Work done	**Description**	**Time**
	Open Device	Teardown + Photos	2
	Features	Device Features + Reports + Main Photo	3
DEVICE	List of Components	Upload components + Reports + Top view	4
	Identifying	Unknown components	3
	X-Cut PCB	Crosscut + Polish + Photos + Measures	3
	Unsold	Unsoldering from PCB	0.5
	X-Ray	Top + Side views	1.5
	Bottom	Bottom view Photos	0.5
COMPONENTS	X-Cut substrate	X-Cut + Polish + Photos + Measures	3
	Information	Diagrams + Reports	3
	Chemical Lab.	Decapsulation + Photos + Measures	8
	FIB Analysis	Send + Receive analysis	1
		TOTAL Approximated Time:	32.5

Performance Analysis

Operating System

In the performance analysis of a mobile device an important background that has to be taken into consideration is the mobile OS that is running the device. Some of the most common ones include Windows, Android, iOS (Apple) and Blackberry as they are already explained in chapter 1.1. Along with the Mobile OS, the Application Engine (AE) features will give a range of comparisons with similar models. Most of the devices the BDB Team is requested to benchmark are based on an Android OS, because of its direct competition with ST-Ericsson. Android is a Google owned company, and the name versions of mobile OS are based on desserts and sweets. They also run in alphabetical order with each new version. The Alpha and Beta versions were prior to the Cupcake.

Fig. 0.2 Android Mobile OS versions

In 2011, Android has reached an incredible 52% of the mobile OS market share worldwide. The main reason for this growth and success is that most Android apps are free.

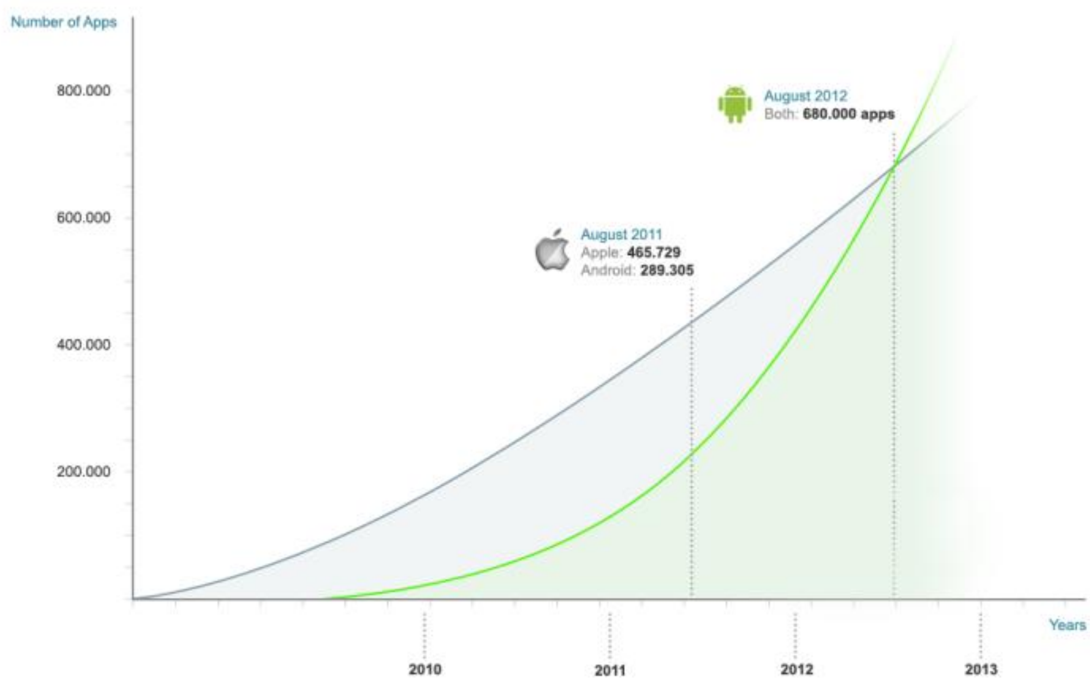


Fig. 0.3 Apple vs. Android in Number of Apps (Xyologic)

Function partitioning

Software Benchmarks are divided into groups that focus on special aspects of the mobile devices that are of common interest to users. Customers trust smartphones and tablets to perform as much and as fast as possible without crashing down. Alongside this experience, users also expect to experience the most realistic images, sounds and features.

Software benchmarks have categories that show specific results in the most important user's interests. These categories are given by the software benchmark developers regarding their application. Some of these applications are specific and some are more general performance bench markings.

Another group of tests are run over the internet. These tests are mainly used for the Browser performance and are called "on line" executed.

Some manual tests also exist to obtain the performance of transmitting information; these tests are called "manually" executed and are dedicated to connectivity. There is a subtype of connectivity manual test that is called co-existence, which is basically the measurement of the performance of a specific feature while using another feature of the connectivity module, i.e. Wi-Fi and BT.

Conditions	Type	Description	Samsung Ace	HTC HD
WiFi ONLY	TCP	Upload	5574	13654
		Download	22891	20821
	UDP	Upload	53679	53721
		Download	Fail	Fail
BT ONLY	Mobile to PC		810	800
	PC to Mobile		426	800
WiFi & BT	TCP	Upload	113.15	1144
		Download	597	1793
	UDP	Upload	53682	53626
		Download	Fail	Fail
BT Stereo			OK	OK

The results type of each test has unit values that can be in time (seconds), frames (fps), Bytes per second (Mb/s), pixels (MP/s) or simple scores and depending on the test either Higher is a better performance or Lower is a better performance.

	Benchmark SW Tests for BDB						Device	Sam.Galaxy Tab 10.1/LE
							DBB	XMM6260-Tegra2
							CPU	2xCA9/1GHz
							GPU	GeForce ULP
							OS	Android 3.0.1
							Introduction date	Q2 2011
Test Name	**Test Category**	**Version**	**Availability**	**Execution**	**Result Type**	**Unit**	**L/H is better**	
Java	**Java**							
Caffeinemark	Java	1.2.4	Free	Appl	Score	no	Higher is better	nt
LinPack Total	Java	1.2.3	Free	Appl	Flops	MFLOPS	Higher is better	35.239
LinPack Time	Java	1.2.3	Free	Appl	Time	s	Lower is better	2.38
LinPack Norm Res	Java	1.2.3	Free	Appl	no	no		5.68
LinPack Precision	Java	1.2.3	Free	Appl	no	no	Lower is better	2.22E-16
EEMBC Grinderbench Chess	Java	1	Under License	Appl	Score	no	Higher is better	21243
EEMBC Grinderbench kXML	Java	1	Under License	Appl	Score	no	Higher is better	21019
EEMBC Grinderbench Parallel	Java	1	Under License	Appl	Score	no	Higher is better	35543
EEMBC Grinderbench Png Decoding	Java	1	Under License	Appl	Score	no	Higher is better	36285
CPU	**CPU**							
BenchmarkPi	CPU	1.11	Free	Appl	Time	ms	Lower is better	526
CPU Benchmark	CPU	1.7.1	Free	Appl	Time	ms	Lower is better	422
MANDRO Bench Socre	CPU	1.1	Free	Appl	Score	no	Lower is better	12082
MANDRO Bench Encryption Single Only	CPU	1.1	Free	Appl	Time	ms	Lower is better	2413
MANDRO Bench Encryption Dual Core	CPU	1.1	Free	Appl	Time	ms	Lower is better	1201
MANDRO Bench Memory-Stride Single Only	CPU	1.1	Free	Appl	Time	ms	Lower is better	2020
MANDRO Bench Memory-Stride Dual Core	CPU	1.1	Free	Appl	Time	ms	Lower is better	1751
MANDRO Bench Collection Single Only	CPU	1.1	Free	Appl	Time	ms	Lower is better	1646

Fig. 0.4 Samsung Galaxy Tab 10.1 SWBenchmark partial results (ST-Ericsson)

A special performance test is the Power Consumption Test, in which the device is connected to a controlled power source (Agilent D3631A PWR Supply) and with the use of an adaptor (General-Purpose Interface Bus "GPIB"-USB) this PWR Supply transmits the information of the power consumption of the device to a PC. A power consumption measurement chart is created by using a PYTHON algorithm to obtain the power consumption of the device 5-10 times per second. The chart will later be represented in a graphic consumption.

While running this test some features of the device will be enabled to see the consumption while performing them.

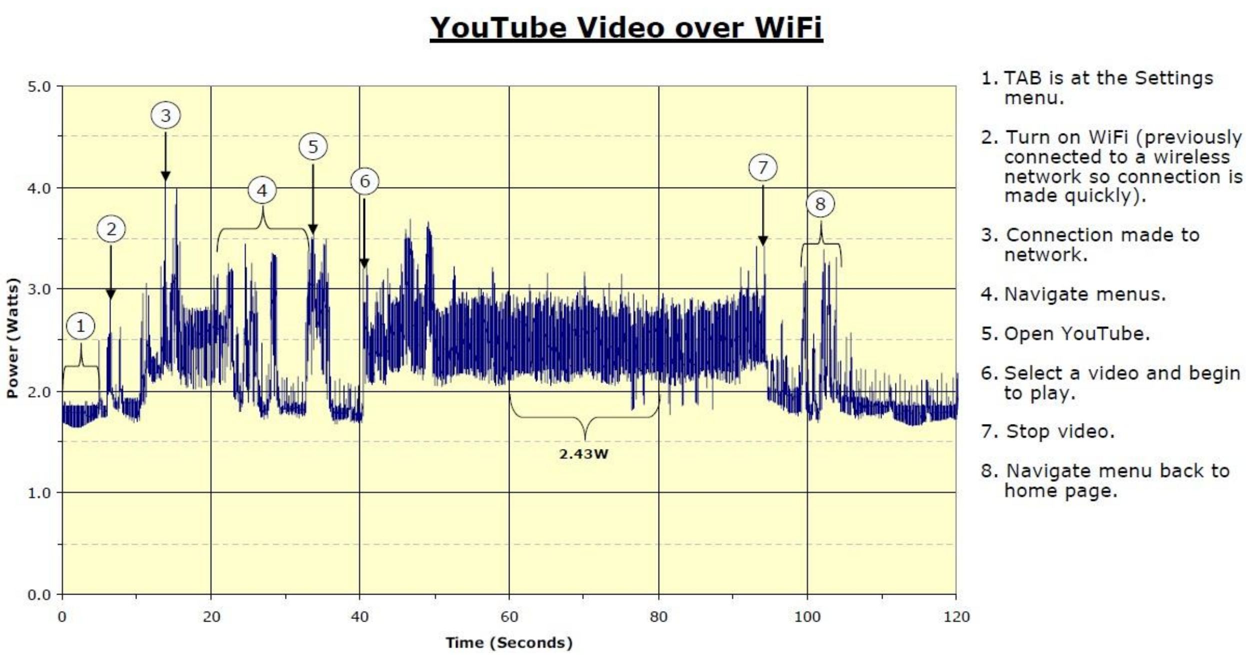


Fig. 0.5 iPhone 4S PWR Consumption chart (TechInsights)

Some test parameters that are taken into consideration for this specific test are: Wi-Fi = Off, Location Services = Off, Bluetooth = Off, Display Brightness = 25% and Volume Level = 25%.

Android Standard applications

An incredible number of Android Software Benchmarks are available for download. Some of them are paid and some are free. During a comprehensive study, and specific requests from ST associates, a list of benchmarking tests was defined to run in all of the android mobile devices that were subject to test. Each benchmark will release newer versions periodically to obtain better test results. Result comparisons on similar devices can only be done using the same version of benchmark.

Java	Graphics 2D/3D	CPU	Browser	General
Caffeinemark	FPS2D	BenchmarkPi	BrowserMark	Quadrant PRO Total
LinPack Total	GLBenchmark	EEMC CoreMark	Sunspider Total	AnTuTu Total
EEMBC Grinderbench	Neocore	CPU Benchmark	html5-benchmark	SD Card
Connectivity	NenaMark	MANDRO Benchmark	V8 Total	Softweg Benchmark Graphics
USB Flash Benchmark	Quake3	SciMark		SmartBench 2011 Productivity
Bluetooth	An3DBench XL Total	**Memory**		Basemark UI
Wi-Fi Iperf/Jperf		MemBench Copy		0xBenchmark
Wi-Fi / BT Co-Existance				Vellamo

Fig. 0.6 SWBenchmarks Apps

Fig. 0.7 Android SWBenchmarks logos

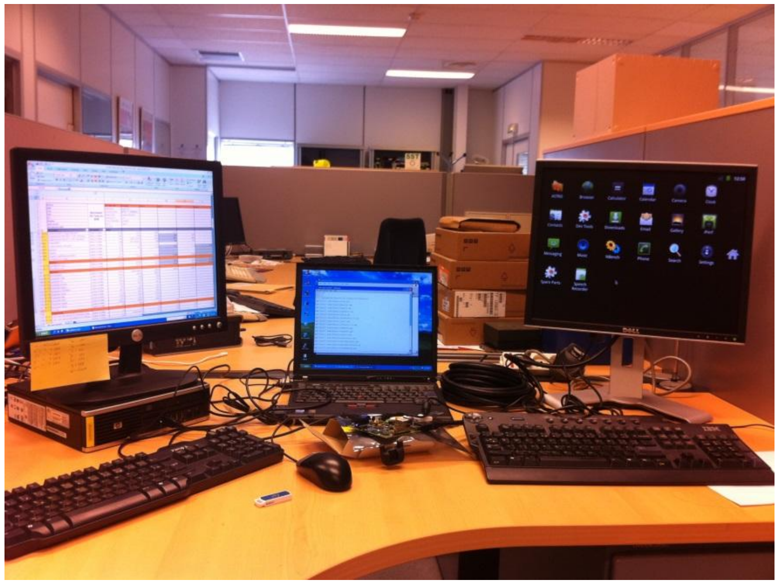


Fig. 0.8 ST-Ericsson BDB SWBenchmark test

Physical Implementation

Device level

General understanding

An analysis of a mobile device starts with a general description and understanding of the device. Smartphones are separated based on their size, shape and style under three major categories, also called form factor: candy bar, flip and slider. Candy bar is the most common form and has a cubic shape. Touchscreen capabilities are a subtype of form, and since 2013, 9 out of 10 smartphones is designed in this form. A flip or clamshell phone has two sections connected to flip-open or fold-close in order to be physically smaller. A slider phone uses two parts that slide one from the other on rails.

Description

Some of the most important aspects to analyze are described below:

- The dimension and weight of the device is a customer’s increasing demand that forces manufacturers to innovate.

- Price is the main obstacle a customer has to deal with when purchasing a new mobile device.
- In Screen capabilities include: resolution (number of colors, size and resolution) and type of screen (capacitive or resistive)
- In telecommunications: bands and data processing capabilities.
- Battery type (Li-ion, NiCd, NiMH), stand by time and talk time:
    - NiCd (Niquel Cadmium) are an old technology and before recharging had to be completely discharged.
    - NiMH (Nickel Metal Hydride) with higher capacity and ecofriendly.
    - Li-ion (Lithium Ion) Lighter with longer lifetime but more expensive.
- Memory: Size (GB) and expandable memory capability.
- Multimedia features: Camera (resolution, autofocus, zoom, flash, secondary camera, video capture, frame rate), Video (MPEG-4, H.263, H.264, WMV) and Audio (MP3, WAV, WMA, AAC) playback, broadcasting support, stereo speakers and dual microphone.
- Connectivity: IrDA, BT, WLAN and USB.
- Other features: Sensors (motion, magnetic, proximity and ambient light), web browser, dual SIM, GPS (A-GPS), SMS, Predictive text and Hands free.

Product Description	
Product Type	World Smartphone
Product Name	iPhone 4S A1387 (Verizon 16 GB)
Brand	Apple
Official Release Date	10/7/2011
Origin	China
FCC ID Number	BCG-E2430A
Serial Number	C39GJMJJDTF9
Operating System (OS)	Apple iOS 5.0
Product Key Features	
Talk Time (Hours):	8 - 3G; 14 - 2G (GSM)
Standby Time (Hours):	200
AirPlay Mirroring	iCloud Wireless Syncing & Storage
Multi-touch Touchscreen	HD (1080p) Video Recording
16 GB User Memory	Siri Interactive Voice Assistant
Bluetooth 4.0	WiFi 802.11b/g/n (2.4 GHz Only)
A-GPS & GLONASS	3-Axis Gyroscope & Accelerometer
Electronic Compass	Proximity & Ambient Light Sensors
System Footprint Metrics	
Weight (grams)	138.8
Product Dimensions (mm)	115.7 x 59.2 x 9.4
Key Subsystems	
Display	3.5" TFT-LCD; 16.7M colors; 960 x 640 pixels; chip-in-glass
Battery	Li-Polymer, 3.7 V, 1430 mAh
Main Camera	8 MP CMOS w/ Autofocus & LED Flash
Front Camera	VGA CMOS

Protocols	
Core Protocol	GSM / W-CDMA / CDMA
Data Protocol	EDGE / HSDPA / HSUPA / 1xEvDO Rev. A
GSM	850 / 900 / 1800 / 1900 MHz
W-CDMA	850 / 900 / 1900 / 2100 MHz
CDMA	850 / 1900 MHz

Teardown and BOM

A teardown procedure consists of disassembling a device. There are two types of analysis in a teardown, destructive and non-destructive. During a teardown detachable parts of a device are separated to recognize and understand its functions. There is a teardown sequence to follow each device to avoid damaging it in the process.

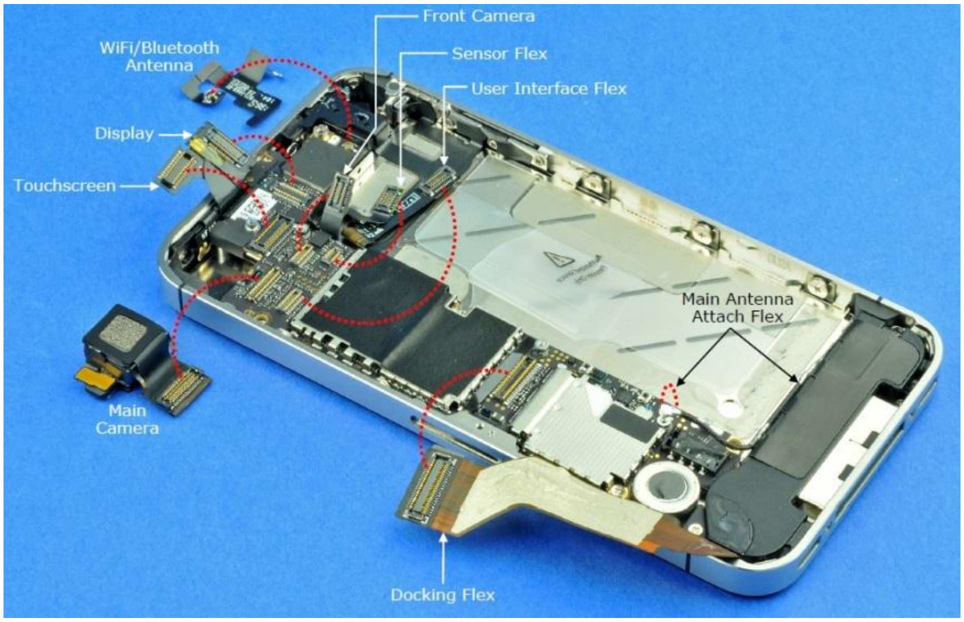


Fig. 0.9 iPhone 4S Teardown procedure (TechInsights)

In the non-destructive teardown parts can be reassembled totally.

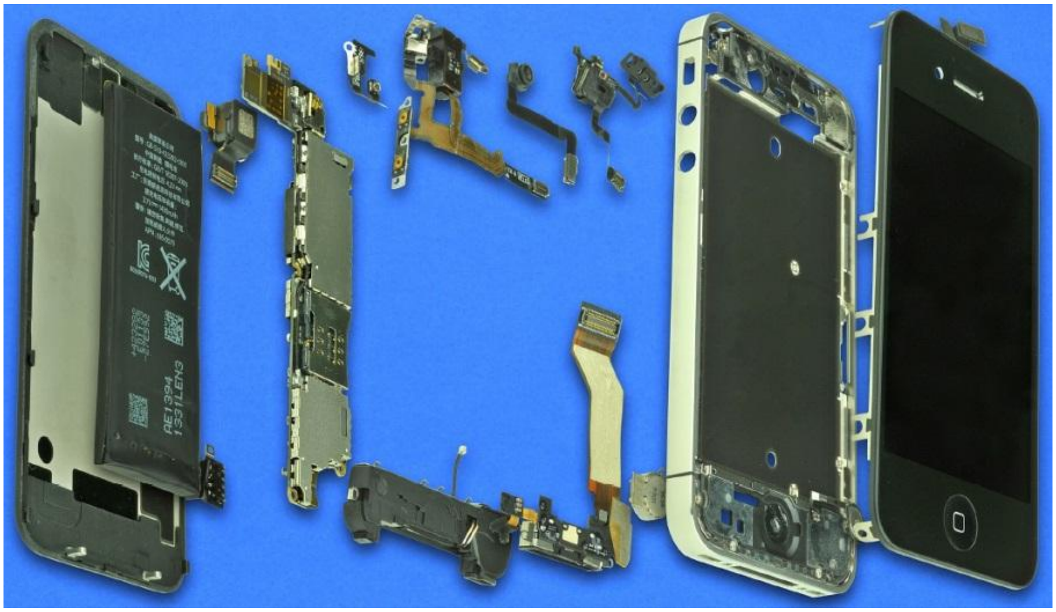


Fig. 0.10 iPhone 4S Component Arrangement

The teardown is photographed step by step on a grid sheet and each component as well.

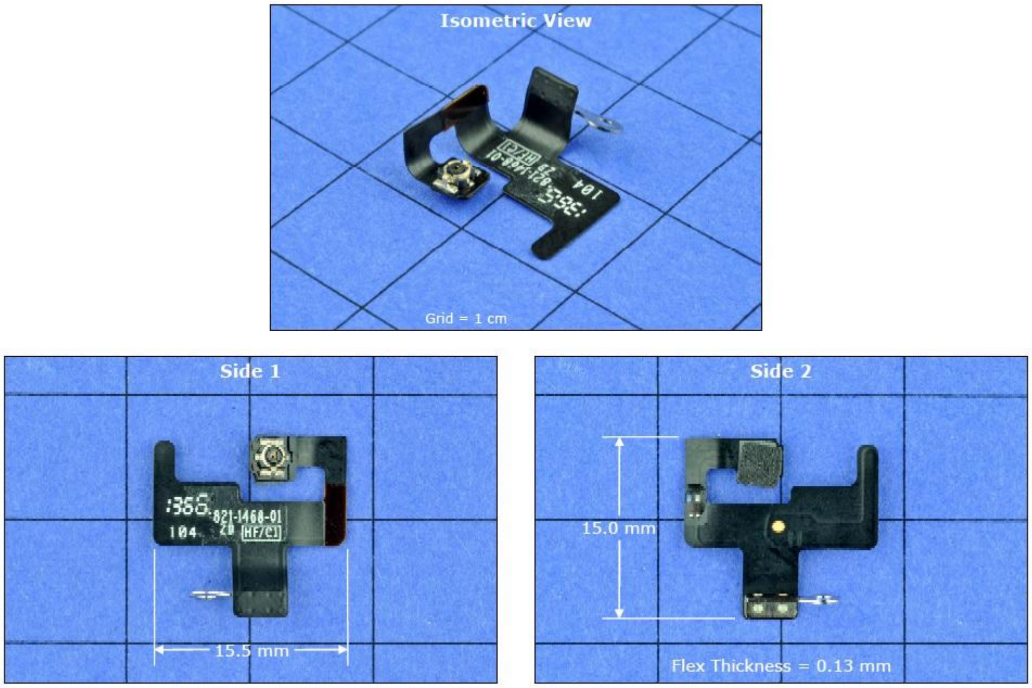


Fig. 0.11 iPhone 4S BT/WiFi Antenna (TechInsights)

A Bill of Materials (BOM) is a list of all components found during the teardown. Because of the extensive number of components in a mobile device, they are arranged under subcategories according to their complexity, Integrated Circuits (IC), subsystem IC (regulators, protectors), connectors, non-electric, passives (resistors, capacitors), small actives (MOSFET, diode), etc…

In a BOM there is the following information on each package: functional area, location, quality, brand name (manufacturer), part number, description or function, markings, package type, number of pins, dimensions, pitch, number of dies, die manufacturer, die part number, die marking, die function and die dimension.

Functional Area	Location	Package Info									
		Pkg Ref. #	Pkg Qty	Brand Name	Part Number	Pkg Description	Form	Pin Count	Pitch (mm)	Length (mm)	Width (mm)	Height (mm)
Analog	Main Board, Side 1	1	1	Cirrus Logic	338S0987 / CLI1560B0	Audio CODEC	Flip Chip, Solder (UF)	77	0.40	4.73	3.05	0.60
		2	1	STMicroelectronics	L3G4200DH	3-Axis Digital MEMS Gyroscope	QFN Stacked 2	16	0.65	4.00	4.00	1.10
		3	1	STMicroelectronics	LIS331DLH	3-Axis MEMS Accelerometer	QFN Stacked 2	16	0.50	3.00	3.00	1.00
		4	1	Maxim	Unknown	DC-DC Converter ?	Flip Chip, Solder (UF)	9	0.50	1.56	1.56	0.60
		5	1	TI	THS7380	Video Amplifier	BGA (UF)	24	0.40	2.60	1.70	0.35
		6	1	Fairchild Semiconductor	FSA6157	SPDT Audio or Video Switch	DFN	6	0.40	1.50	1.00	0.50
		7	1	NXP Semiconductor	74AUP1G08	2-Input AND Gate	DFN	6	0.35	1.00	1.00	0.60
		8	1	TI	TPA2015D1	2 W Class-D Audio Amplifier	Flip Chip, Solder (UF)	16	0.50	1.95	1.95	0.50
		9	1	NXP Semiconductor	74AUP2G07	Dual Non-Inverting Buffers	DFN	6	0.35	1.00	1.00	0.60
		10	1	Maxim	MAX8834Y	Step-Up Converter w/ 1.5 A Flash Driver	Flip Chip, Solder (UF)	20	0.50	2.61	2.07	0.50
Logic		11	1	Samsung	A5 / APL0498	Dual-Core ARM Applications Processor	BGA-POP (UF)	1640	0.40	16.50	14.00	0.80
Memory		12	1	Hynix Semiconductor	H9TKNNN4KDMPYR-NDM	Multichip Memory - 512 MB Mobile DDR2-S4 SDRAM	BGA-POP-2 (UF)	280	0.40	16.50	14.00	0.62
RF - Transmit		13	1	Avago	ACPM-7181	Quad-band GSM / Dual-band W-CDMA (Band I / VIII) Power Amplifier	MCP - 3 Chips	24	0.65	7.50	5.00	1.00
RF - Receive		14	1	Infineon	BGS15AN16	SP5T Antenna Switch	QFN	16	0.50	2.35	2.35	0.80
RF - Shared		15	1	Qualcomm	RTR8605	GSM / CDMA / W-CDMA Transceiver + GPS	BGA (UF)	196	0.40	7.80	6.20	0.95
		16	1	Murata	SPg-QHB52	SP8T Antenna Switch	BCC	18	0.50	3.20	2.40	1.05
		17	1	TriQuint	TQM666052	CDMA 1900 MHz / W-CDMA Band II Power Amplifier w/ FBAR Duplexer	DFN	13	0.50	4.50	3.50	1.00
		18	1	Skyworks	SKY77464	CDMA 850 MHz / W-CDMA Band V Power Amplifier w/ SAW Duplexer	DFN (UF)	14	0.50	4.10	3.20	1.20
Touch Input		19	1	TI	343S0538 / F761530	Touchscreen Controller	Flip Chip, Solder (UF)	63	0.40	3.19	3.19	0.60
Analog	Main Board, Side 2	20	1	AKM Semiconductor	AK8975	3-Axis Electronic Compass	Flip Chip, Solder	14	0.50	1.96	1.94	0.50
		21	1	Qualcomm	PM8028	Power Management	BGA (UF)	136	0.40	7.00	5.00	0.80
		22	1	Dialog Semiconductor	338S0973 / D1881A	Power Management	BGA (UF)	208	0.40	7.40	5.80	0.50
		23	1	Macronix	MX25U808X ?	Serial Flash Memory - 1 MB ?	Flip Chip, Solder (UF)	11	0.50	3.00	1.95	0.50
		24	1	Fairchild Semiconductor	FPF1039	Slew-Rate-Controlled Load Switch	Flip Chip, Solder (UF)	6	0.50	1.46	0.96	0.80
		25	1	TI	TS3APF8235	Headphone Amplifier ?	Flip Chip, Solder (UF)	16	0.40	1.55	1.55	0.50
		26	1	TI	SN74LVC1G123	Monostable Multivibrator w/ Schmitt-Trigger Inputs	Flip Chip, Solder (UF)	8	0.50	1.89	0.89	0.60
		27	1	NXP Semiconductor	74LVC1G04	Single Inverter	DFN	6	0.35	1.00	1.00	0.60
		28	1	STMicroelectronics	ESDALC6V1-5T6	5-Ch. ESD Protection Array	DFN	6	0.35	1.00	1.00	0.60
		29	1	NXP Semiconductor	74AUP2G07	Dual Non-Inverting Buffers	DFN	6	0.35	1.00	1.00	0.60
		30	1	Ricoh	RP106Z	400 mA LDO Regulator	Flip Chip, Solder (UF)	4	0.40	0.68	0.68	0.50
		31	1	NXP Semiconductor	74LVC1G11	3-Input AND Gate	DFN	6	0.35	1.00	1.00	0.60
		32	1	NXP Semiconductor	74AUP1G08	2-Input AND Gate	DFN	6	0.35	1.00	1.00	0.60
		33	1	NXP Semiconductor	74AUP1T97	Configurable Gate w/ Voltage-Level Translator	DFN	6	0.35	1.00	1.00	0.60
Logic		34	1	Qualcomm	MDM6610	GSM / CDMA / W-CDMA Baseband Processor + Memory	BGA Stacked 2 (UF)	383	0.40	9.00	9.00	1.20
Memory		35	1	Toshiba	THGVX1G7D2GLA08	Multichip Memory - 16 GB MLC NAND Flash + Controller	BGA Stacked 2+1 (UF)	52	1.50	18.00	14.00	1.00
RF - Shared		36	1	RF Micro Devices	RF1642 ?	DPDT Antenna Select Switch	QFN	12	0.50	2.00	2.00	0.50
WiFi/Bluetooth		37	1	Murata	SS1826005	802.11n WiFi / Bluetooth 4.0 / FM Module	MCP - 4 Chips (UF)	52	0.50	8.80	8.00	1.10
A-GPS		38	1	Avago	MGA-310G	A-GPS LNA	QFN	6	0.50	1.13	1.09	0.50

Fig. 0.12 iPhone 4S partial BOM List (TechInsights)

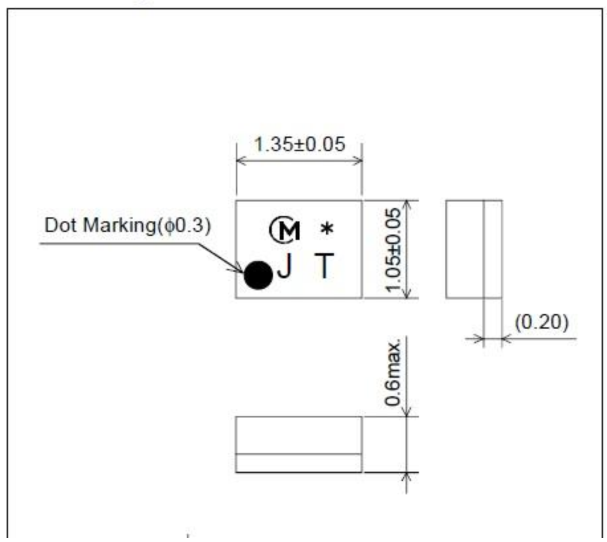
Identification

To obtain a BOM of a certain device it is necessary to identify every single component. Components have markings that include logos, brands, dates, serial numbers, underscores, binary codes, etc… Some components only have characters that can be used to identify those using charts of specific manufacturers.

SAW FILTER FOR GPS

Murata part number :SAFEB1G57KE0F00

■ Package Dimensions



Philips Semiconductors

Small Signal Transistors and Diodes — Marking codes

DIODE TYPE NUMBER TO MARKING CODE

TYPE NUMBER	MARKING CODE	PACKAGE
1N821	1N821	SOD68 (DO34)
1N821A	1N821A	SOD68 (DO34)
1N823	1N823	SOD68 (DO34)
1N823A	1N823A	SOD68 (DO34)
1N825	1N825	SOD68 (DO34)
1N825A	1N825A	SOD68 (DO34)
1N827	1N827	SOD68 (DO34)

TYPE NUMBER	MARKING CODE	PACKAGE
1N5817	1N5817	SOD81
1N5818	1N5818	SOD81
1N5819	1N5819	SOD81
1PS59SB10	10	SC-59/SOT346
1PS59SB14	14	SC-59/SOT346
1PS59SB15	15	SC-59/SOT346
1PS59SB16	16	SC-59/SOT346
1PS59SB20	20	SC-59/SOT346

Sometimes there is no possible way to identify a component, but based on its location, dimension or shape it is possible to identify its function.

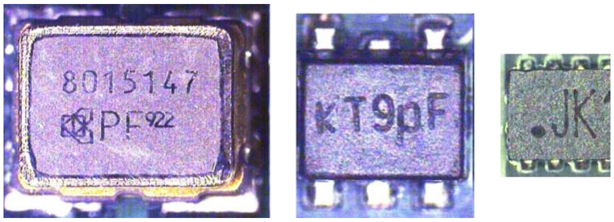


Fig. 0.13 Unidentified SMD (ST-Ericsson)

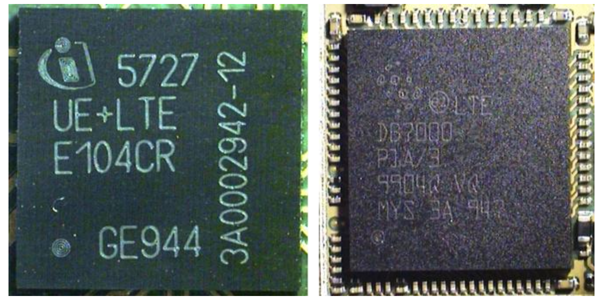


Fig. 0.14 Package Markings (ST-Ericsson)

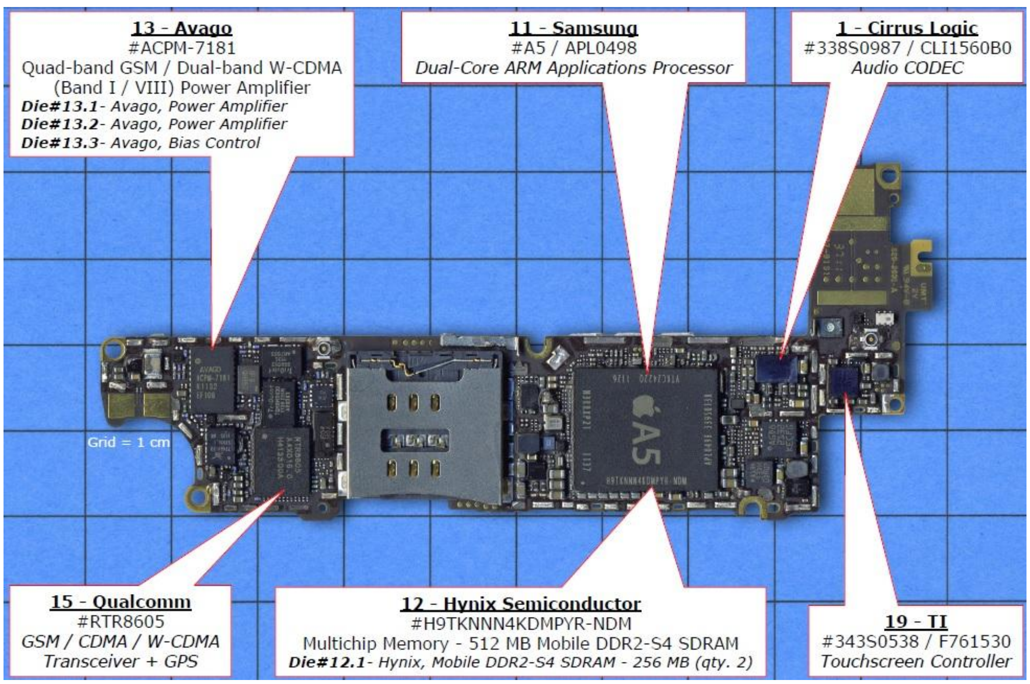


Fig. 0.15 Component Identification

A printed circuit board (PCB) is the mechanical platform that supports all the components. It uses copper pads or tracks to connect them electrically. PCB's can be one of three types: single sided with only one copper layer, double sided with two layers, or multi-layer. In mobile devices the used PCB type is the multilayer. The PCB complexity has evolved to provide a smaller product with better features, which also means more layers to connect. To interconnect between layers PCB's use plated-through holes called vias. There are three types of vias; blind, through and buried.

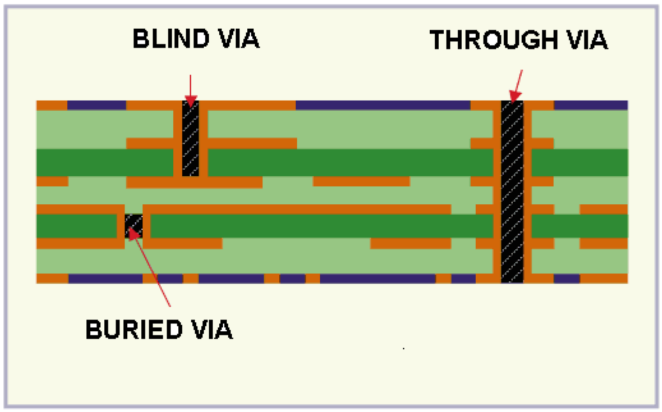


Fig. 0.16 Types of vias

In order to obtain a cross section of the PCB a Saw cutter machine is used. This machine basically cuts the PCB with a thin wire that rotates on two rolls pulling the wire up and down.

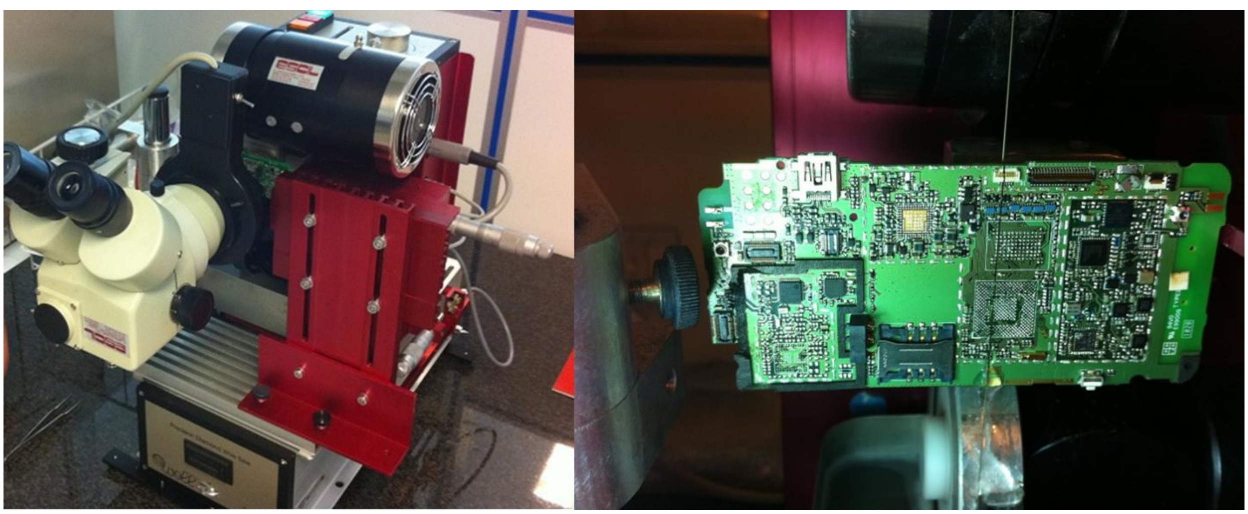


Fig. 0.17 SAW Cutter machine

A cross sectional picture is taken with a microscope to later measure the distance between layers and via diameters with a special software. These parameters will be later used to calculate costs.

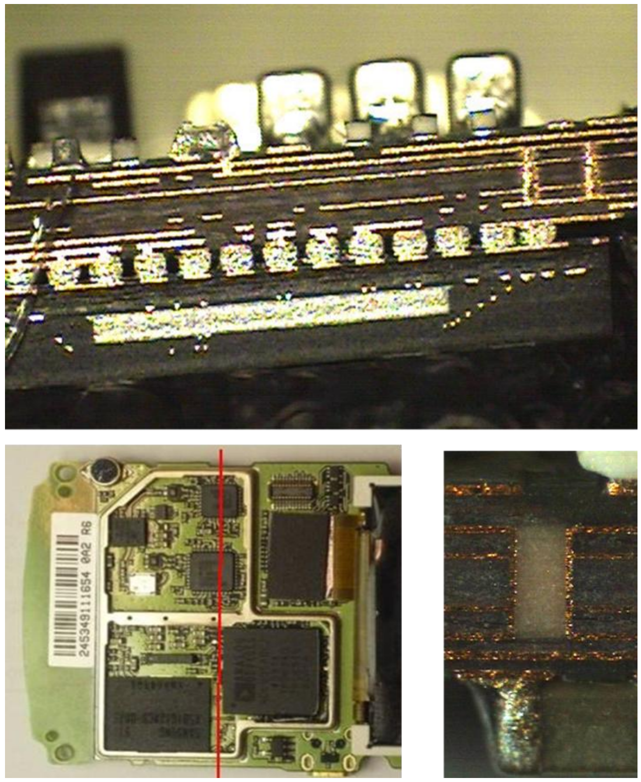


Fig. 0.18 PCB Cross-cut examples

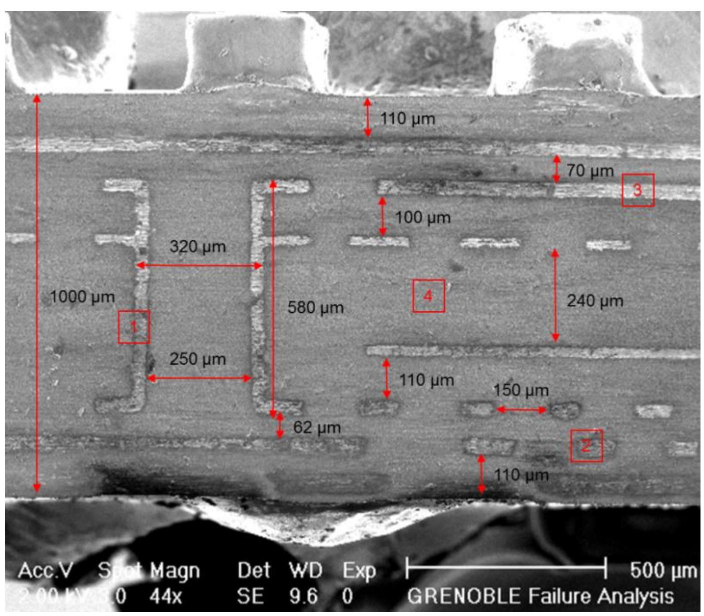


Fig. 0.19 2+4+2 PCB with measures

This machine will have exchangeable sandpaper disks of different roughness to obtain the exact desirable wear material.

Fig. 0.20 PCB and Component Polisher

A 4+2+4 buildup with 0.8mm thickness PCB.

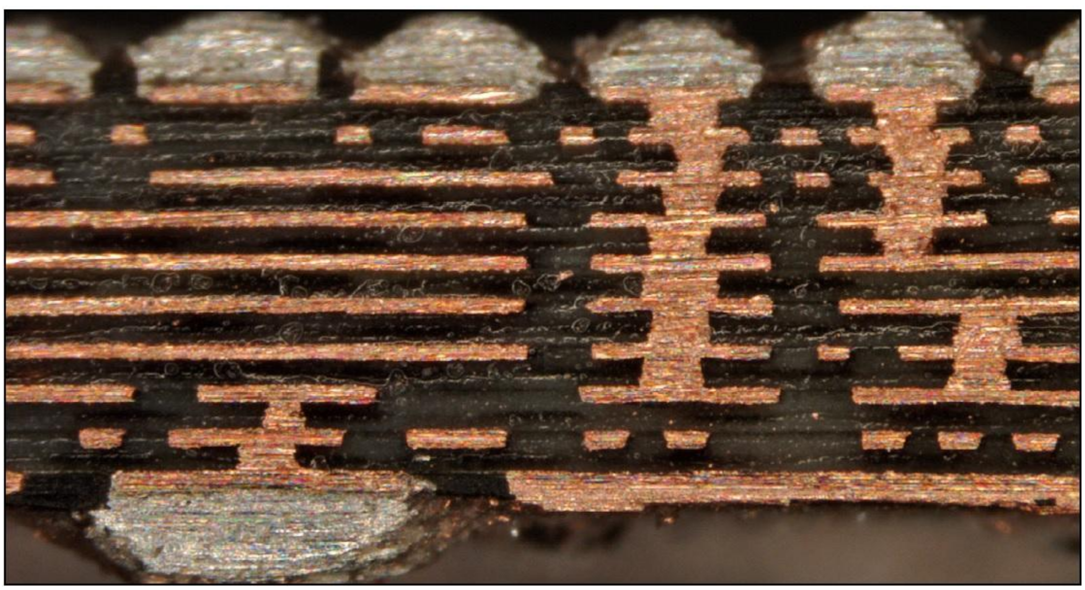


Fig. 0.21 PCB Cross-cut (TechInsights)

Components level

Define domain of interest

As explained in section 1.4, ST-Ericsson is a major producer of complete mobile device platforms. For this matter, the main interest components from the competition are: DBB, PMU, RF, AE, BT, WLAN, FM Receiver, GPS, and other components upon special requests are analyzed, including camera modules.

Once all of the important components are identified, top pictures of the component have to be taken in the microscope. A small but important probability exists of damaging the package in the process.

Fig. 0.22 Microscope

Depending on the type of PCB, three types of desoldering a Surface-Mounted Device exist:

- An infrared machine (PDR IR – X310L) is used to desolder a SMD. It is mostly used when the PCB is two-sided.

Fig. 0.23 Infrared machine

- Use of a heat air pistol or gun can be used in both single side and two sided PCB. It is mostly used when the SMD is large, and is not reliable for PoP Packages (refer to section 3.1.1). After selecting the temperature and airflow, the air flows on top and around the SMD until it desolders from the PCB.

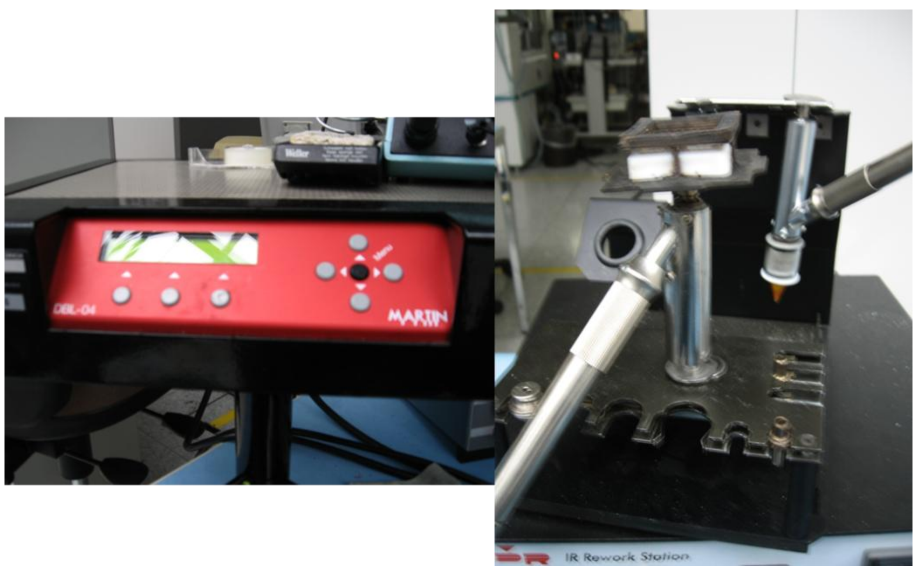


Fig. 0.24 Hot Air gun

- Hot plate method for desoldering uses a hot plate where the PCB is located. Once the PCB is hot enough to melt the balls the SMD can be easily taken.

The disadvantage of using this method is that it can only be used in a single sided PCB and usually destroys other small components that cannot support high temperatures.

Component construction

Each package has a function to perform, depending on the component function there is a classification. Between the most important functions are:

- Electrical: provides an electrical path from the die inputs and outputs to the package termination
- Thermal: provides a thermal path from the die to the ambient (heat dissipation)
- Mechanical: protect the die (shock, humidity, etc) and to insure a standard mounting (package shape and outline according to standards)
- Reliability: insure proper lifetime of the package (protection against corrosion, thermal management, bonding reliability (die-package or package-pcb)

The component construction is a very complex task. Different departments are involved during a long-time process to achieve the best possible component. For the purpose of this thesis the construction details will be focused on the benchmarking point of view with special interest in substrates, dimensions, materials and their respective parameters that will set the cost of production.

Die and Package

Package manufacturing is divided into two main sequential processes; the front-end and back-end production. During the Front-End stage, the conceptual design of a package is achieved based on the needs and the initial specifications. The Front-End will focus on the technical requirements and the investment cost of the project. During this phase, a silicon wafer will be produced. A silicon wafer is the substrate of a microelectronic device used in the fabrication of integrated circuits. They are available in different diameters and have been increasing over the years to improve performance and reduce cost. The back-end of production refers to the assembly and test of individual semiconductors. The Wafer Level Package (WLP) and the flip-chip type of packages also exist and will be briefly explained in the next chapter.

A basic plastic enclosure package Back-End construction is detailed below.

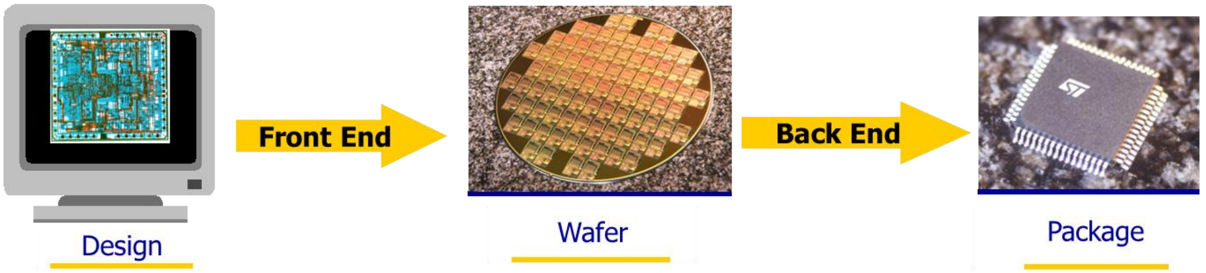


Fig. 0.25 Front End to Back End sequence.

An automatic electric test is performed to 100% of dies in a wafer. Electrical refusal dies are marked with an ink dot.

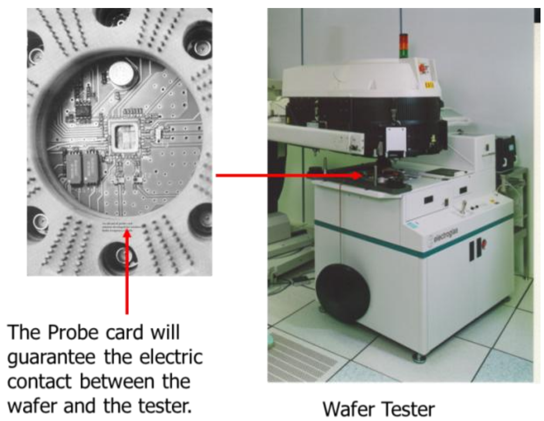


Fig. 0.26 Automatic electric test.

The wafer is bonded to a flexible and adhesive support to be cut by a circular high precision diamond saw machine.

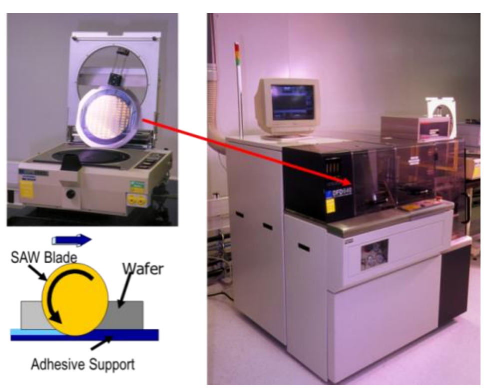


Fig. 0.27 Die cutting or Dicing process (STMicroelectronics)

Cutting control in a microscope includes controlling of the cutting lines, detecting damaged chips and eliminating the board if the number of damaged chips is too high.

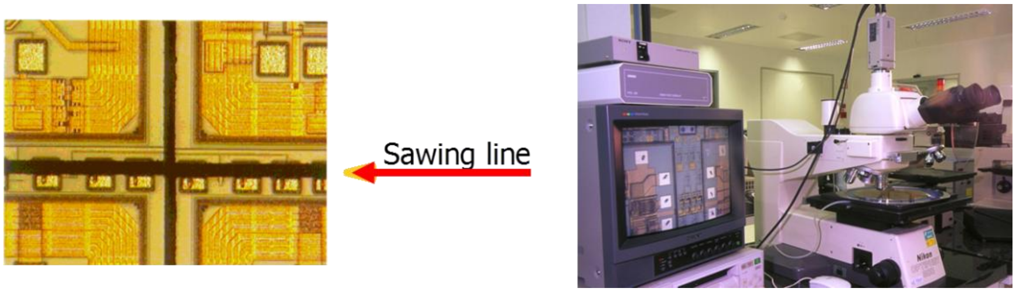


Fig. 0.28 Cutting Control

The chips are bonded together on a metal grid with an epoxy resin. The chips are then placed in an oven to polymerize the resin. A very thin gold wire (Ø25-50μ) is used to make the connection between the chip and the grid. This bonding is diagramed in computer software that includes each coordinate for each bonding in the die and in the substrate.

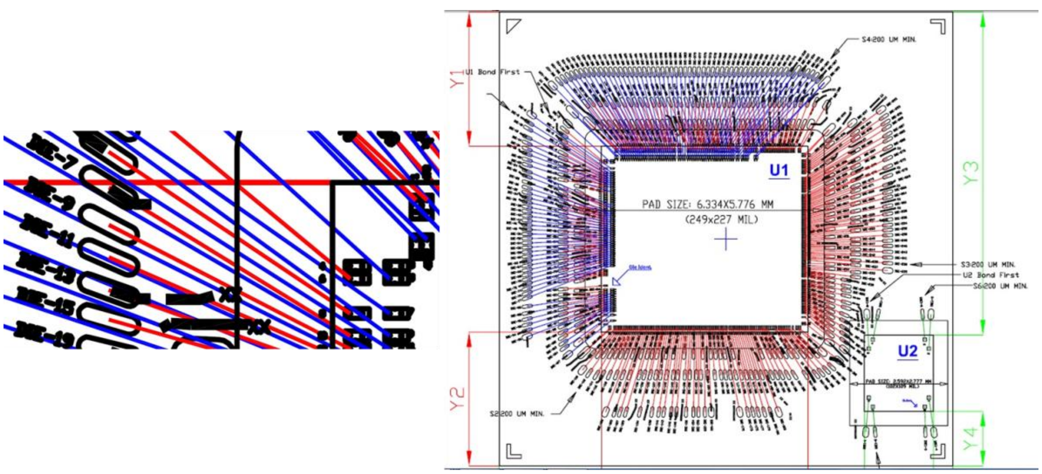


Fig. 0.29 Bonding coordenate parameters

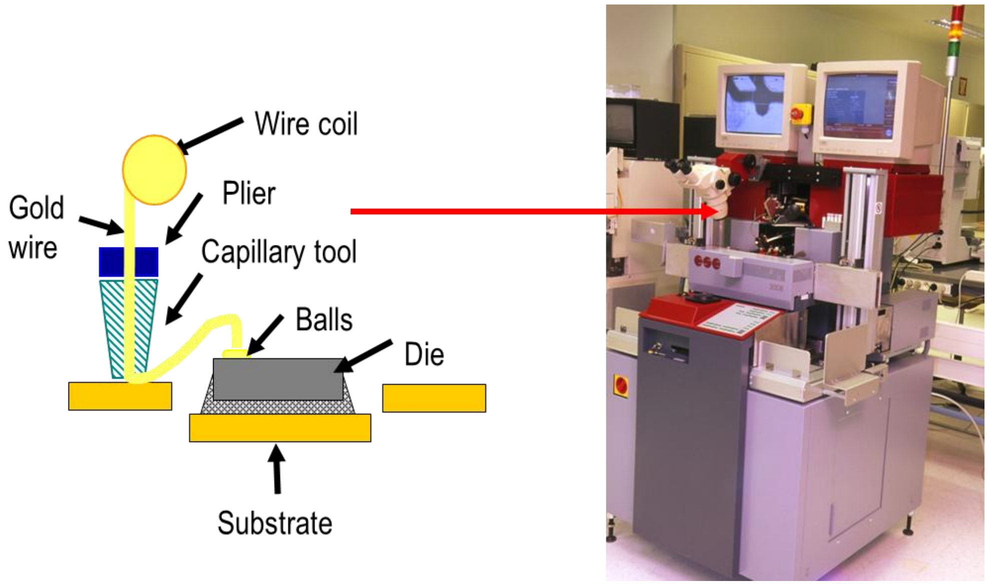


Fig. 0.30 Bonding Process

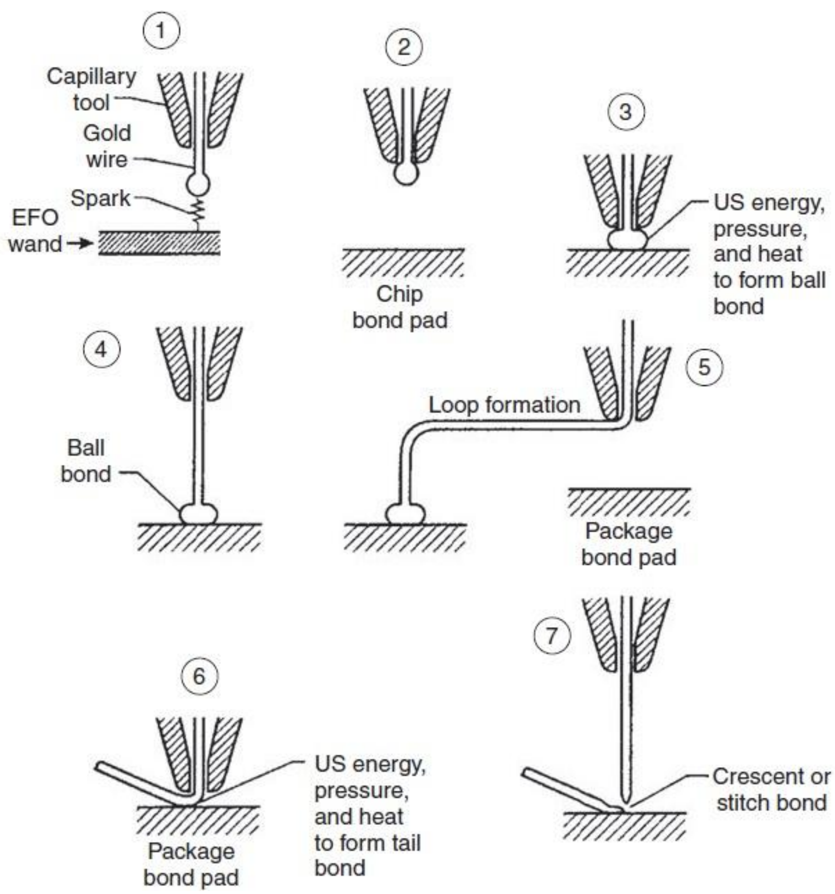


Fig. 0.31 Wire Bonding with capillary tool (Wire Bondings in Microelectronics)

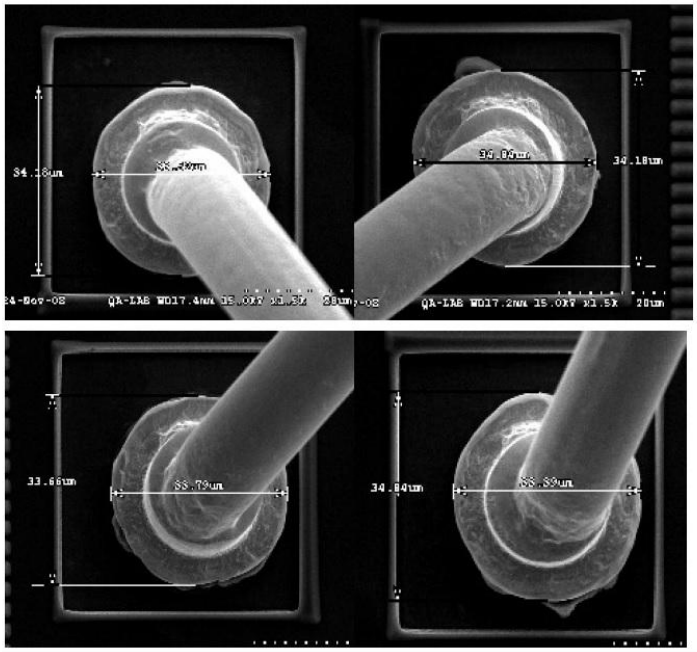


Fig. 0.32 Bonding die balls 3D

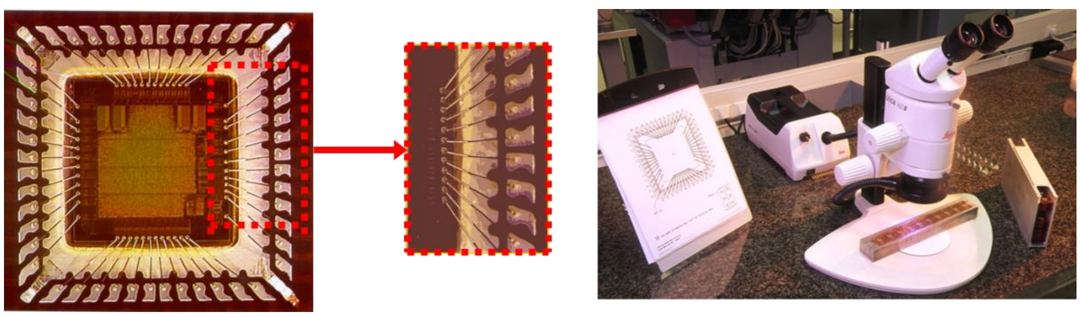


Fig. 0.33 Quality Control Assembly

A mold process is used to encapsulate the leadframe. A mold compound in a liquid encapsulates the device in a mold press shortly after the compound is hardened, and finally in an oven this compound becomes completely hard.

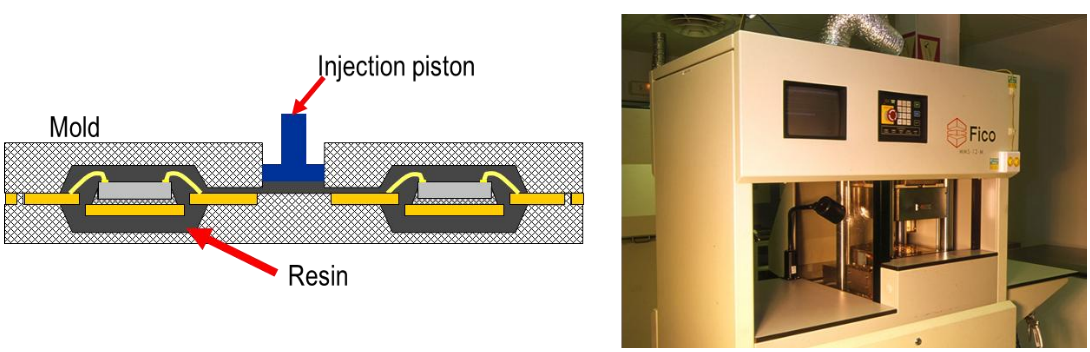


Fig. 0.34 Mold process

The dejunk and deflash processes remove mold excess and cover the package surface with small glass particles; they prepare the leadframe for plating and the mold compound for marking respectively. In the plating process the leadframe is pretreated, rinsed, platted, dried and inspected. The marking is done by a laser controlled by a computer that burns the resin molding surface. Marking information includes: logo, lot reference, product code, and country among others.

Fig. 0.35 Component marking (STMicroelectronics)

Cutting and folding is a process that consists of circuit separation from a grid and folding of connections.

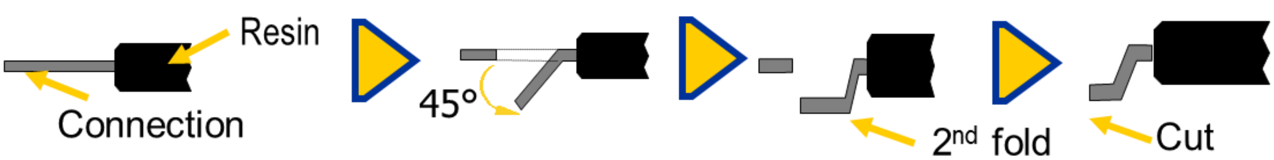


Fig. 0.36 Cutting and Folding process

Finally every package is subject to an automatic electrical test at a temperature according to its application. All refused packages are destroyed. Before taping for transport all markings are verified as well.

Front-End and Back-End stages will give a cost of production which is the main target of the benchmark analysis to obtain total manufactures cost.

CHAPTER 3 - COMPONENT ANALYSIS

Package

The component analysis starts with non-destructive testing. These tests allow us to understand the complexity of a component and obtain the background information of the package.

A physical examination defines the type of package and its properties (for types of packages refer to section 3.1.1). Pictures from the top view and bottom view are also included in the report.

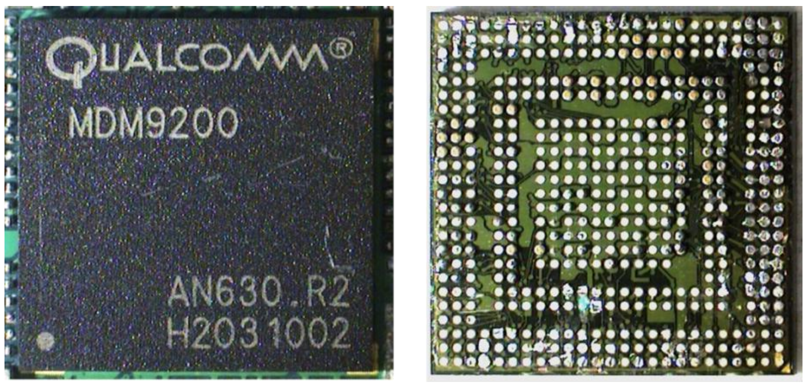


Fig. 0.1 Top and bottom view of package.

An X-Ray test is used to obtain pictures of the component, such as top view, multiple side views and tilt view. Pictures are taken in an X-Ray component machine. With these pictures the structure of a package is going to be represented in a diagram. The number of dies and dimension information will be used to prepare the destructive tests.

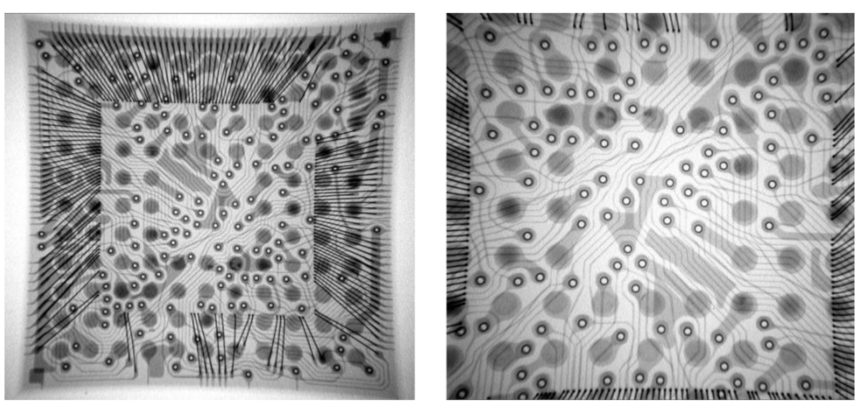


Fig. 0.2 X-Ray Top and Bottom views

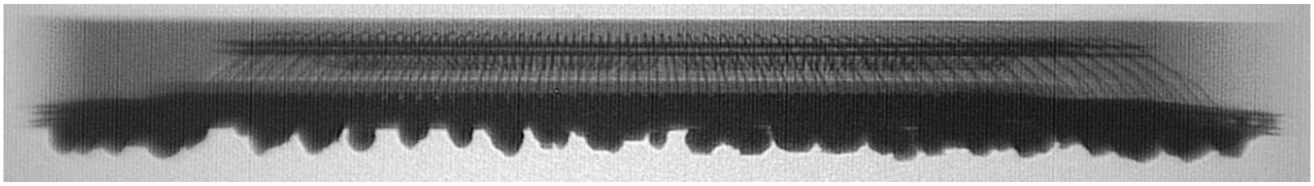


Fig. 0.3 X-Ray Side view

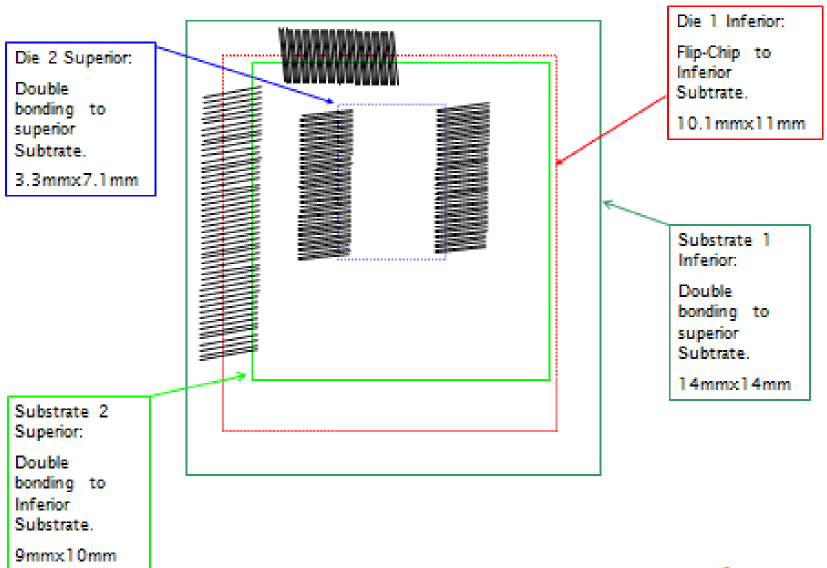


Fig. 0.4 Diagram of Package (Top view)

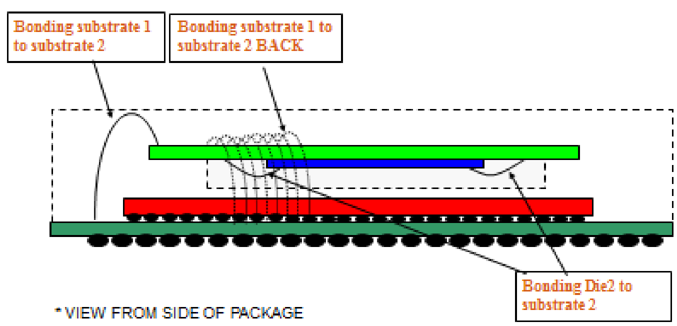


Fig. 0.5 Diagram of package (Side view)

Main parameters for the report are inside the substrate. To obtain these parameters the first destructive test used is the Cross section, or Cross-cut, test. Using the polisher with the sandpaper, a cross-cut will be obtained when the component is grinded down. Under the microscope pictures of the cross sectional views will be taken.

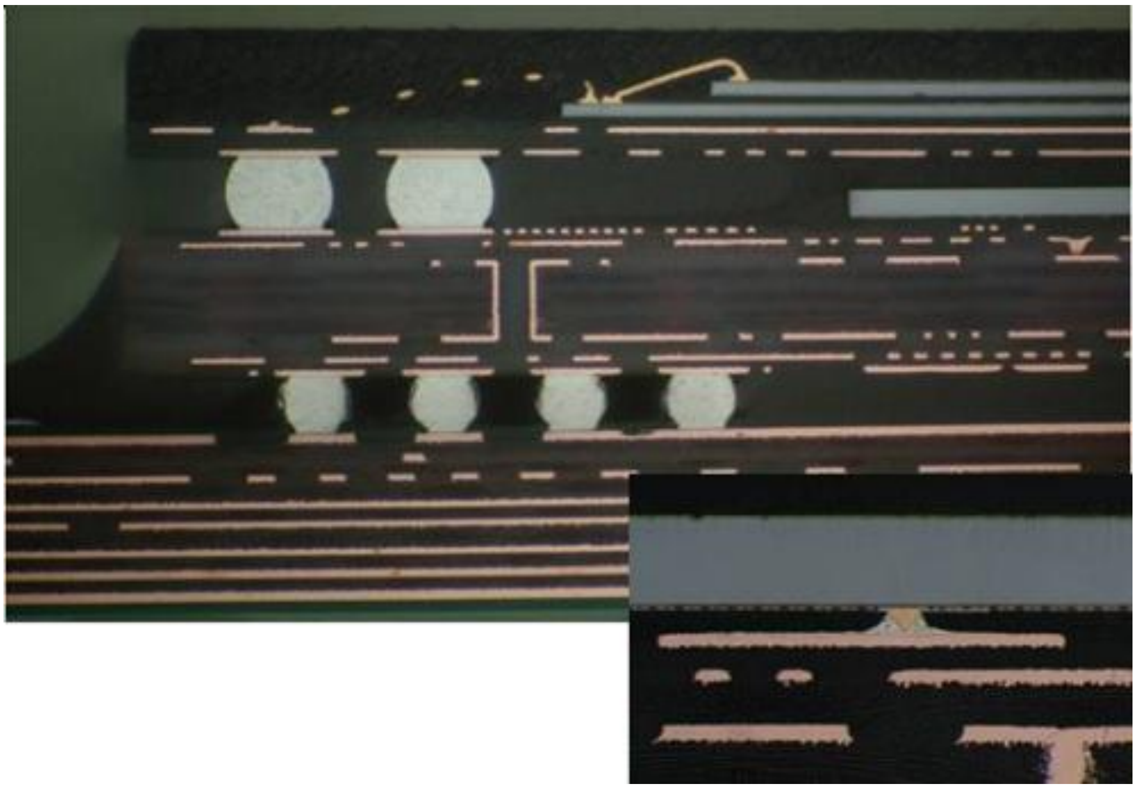


Fig. 0.6 Package Cross Section view

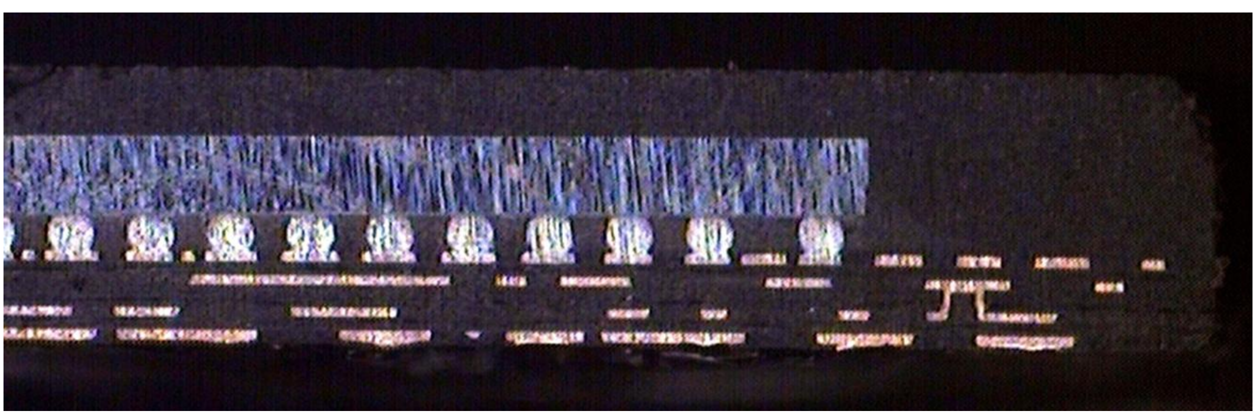


Fig. 0.7 Package Cross Section view

The second destructive test, once all the parameters from the substrate are obtained, is the chemical sample preparation or deprocessing. Depending on the component of molding and bonding, or the removal goals, several chemical tests can be performed (gold wire removal, gold lead removal, gold bump removal, aluminum removal, ball attack, etc). Some chemical parameters are solution composition, temperature, duration, and rinse procedure.

7.4 Gold bump removal

Product: « Aqua Regea »
Solution composition: 10 ml nitric acid 69%
10 ml chlorhydric acid 36%

Use a hot plate:
The thermal sensor must touch the bottom of water recipient, in the center of the hot plate
Temperature: T= 30°C
Wait for the stabilization of temperature of hot plate : [30.8 –31.6]°C

In a recipient: fill 10 ml HNO3 69%
Put the sample in HNO3 first (for just few seconds)
Start the clock when you fill 10 ml HCl 36% in the recipient
The sample must be nearest of the center of hot plate (to control the temperature)
Duration: 12 minutes

Rinse as follow:
Shaking the sample in distilled water during 2 seconds to dilute acid
5 minutes in acetone in ultrasonics
5 seconds in isopropanol
5 seconds in distilled water
5 seconds in acetone

Fig. 0.8 Gold bump removal procedure

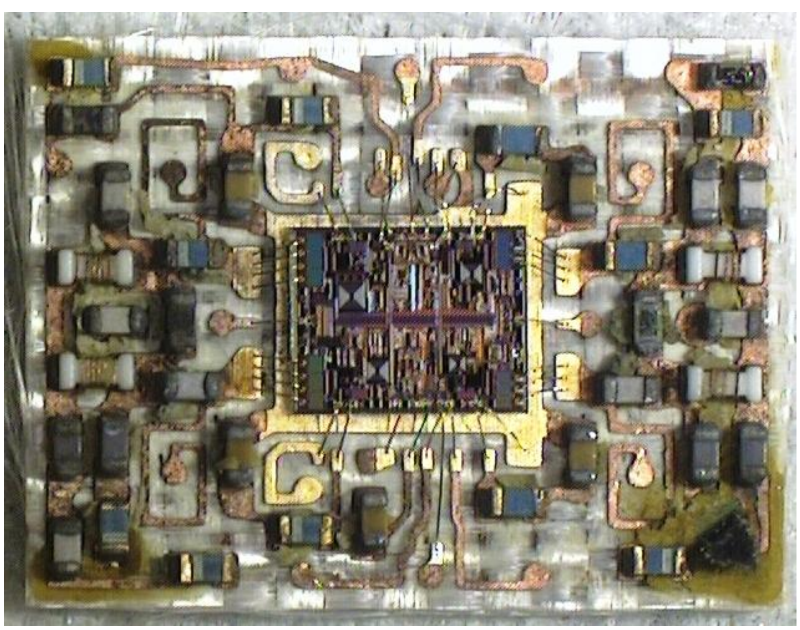


Fig. 0.9 Nitric acid 100% chemical exposure package

A package opening procedure can be also performed using a decapsulation system (JetEtch).

Fig. 0.10 JetEtch Decapsulation System

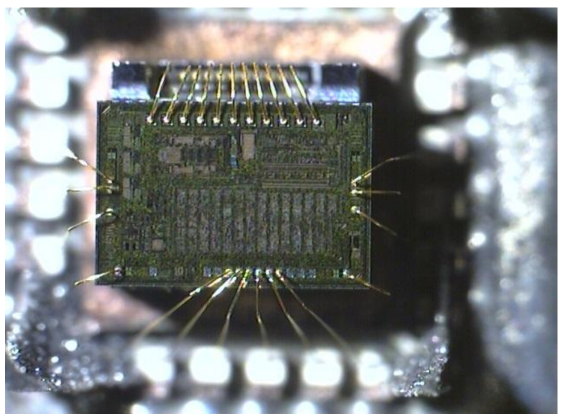


Fig. 0.11 Decapsulation of package

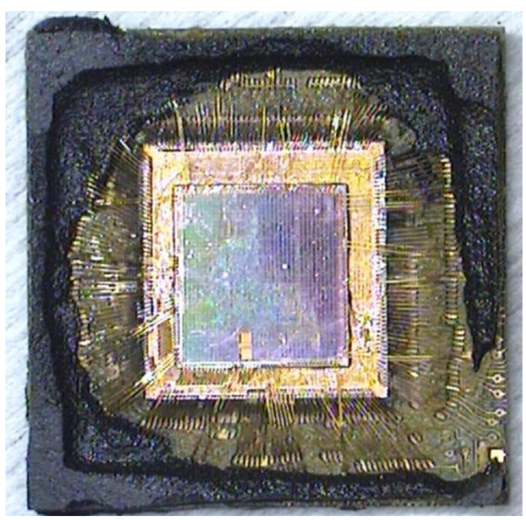


Fig. 0.12 Decapsulation and Rinse of Package

Types of Package

A very huge variety of integrated circuits exists in all types of packages, ST-Ericsson's benchmark focuses on the ones used by their competitors in similar products. For the matter of this study only Surface Mount Devices (SMD) will be studied. These packages are mounted directly on the surface of the PCB. New production technologies allow these packages to increase the PCB component density and its number of connections. Automated assembly becomes easier and faster than through-hole components, plus it allows components to be placed in both sides of the PCB. ST-Ericsson's main SMD competition devices are found in these SMD package types: Small Outline Package (SOP and QFP), Flat Packages No-Lead (QFN and DFN), Wafer Level Chip Scale Package (WLCSP) and Ball Grid Array (BGA).

The SOP is a package technology that reduces the area in 50% compared to an equivalent DIP (Dual in-line Package), the lead pitch and the overall volume. It comes with two-sided leads. Some SOP packages are:

- Very Small Outline Package (VSOP)
- Thin Shrink Small Outline Package (TSSOP)
- Micro Small Outline Package (MSOP)
- Quarter Size Outline Package (QSOP)
- Plastic Small Outline Package (PSOP)
- Thin Small Outline Package (TSOP)
- Shrink Small Outline Package (SSOP)

A Flat Package with Leads (QFP) is based on a SOP with the only difference having leads in all four sides of the package.

Fig. 0.13 ST SOP and QFP Packages

A flat package (No-Lead) type is a leadless package that instead has pins through the edges of the package. This type of package has a thermal pad to improve heat transfer out of the IC and into the PCB. There are two types of flat no–lead packages: Quad Flat No-lead (QFN) and Dual Flat No-lead (DFN); their difference relies on the number of sides which have pins (refer to figures 3.15 and 3.17).

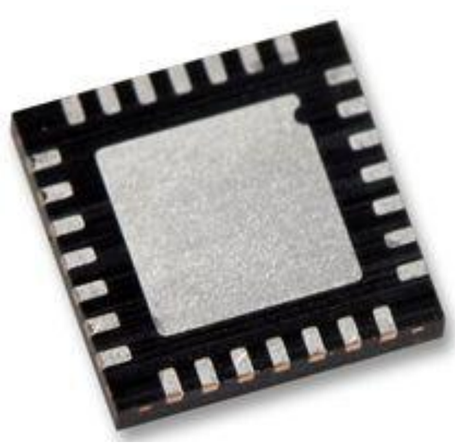


Fig. 0.14 QFN Package with thermal pad in the center

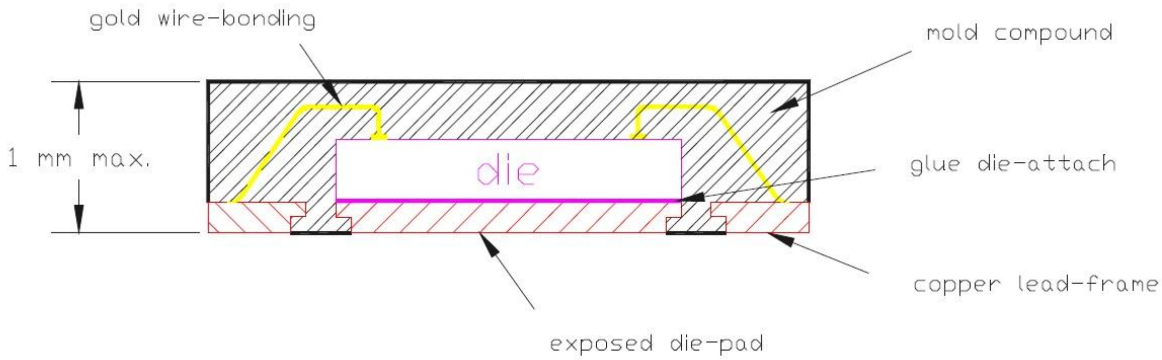


Fig. 0.15 QFN Structure (STMicroelectronics)

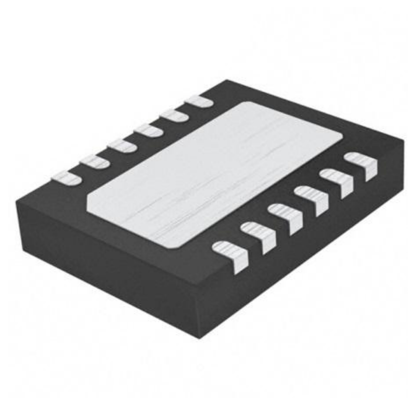


Fig. 0.16 DFN Package

Wafer level packaging (WLP) is an emerging technology that involves the die having the same or 1.2 times greater the size of the package; this is called Chip Scale Package (CSP), and involves packaging it while still in the wafer. Essentially the dies are fabricated, packaged, and tested at wafer level. It also includes device interconnection and device protection processes during the wafer fabrication. Two main types of WLP exist: Fan-In and Fan-Out (refer to Fig 3.17).

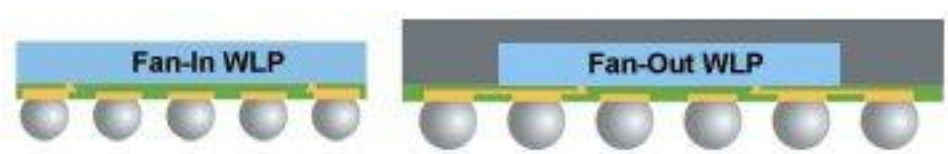


Fig. 0.17 Fan-In WLP & Fan-Out WLP

Ball Grid Array (BGA) is a type of package with a larger capacity of pins that are located in the bottom surface of the package instead of just the edge. Balls are also smaller leading to a better performance. BGA packages are most often used for microprocessors, for this reason it is the most analyzed type of package by ST-Ericsson's Benchmarking department.

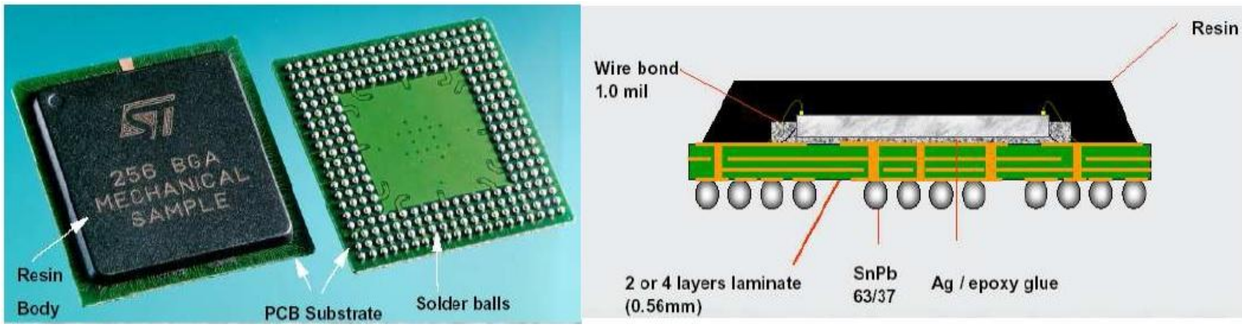


Fig. 0.18 BGA Sample and Structure (STMicroelectronics)

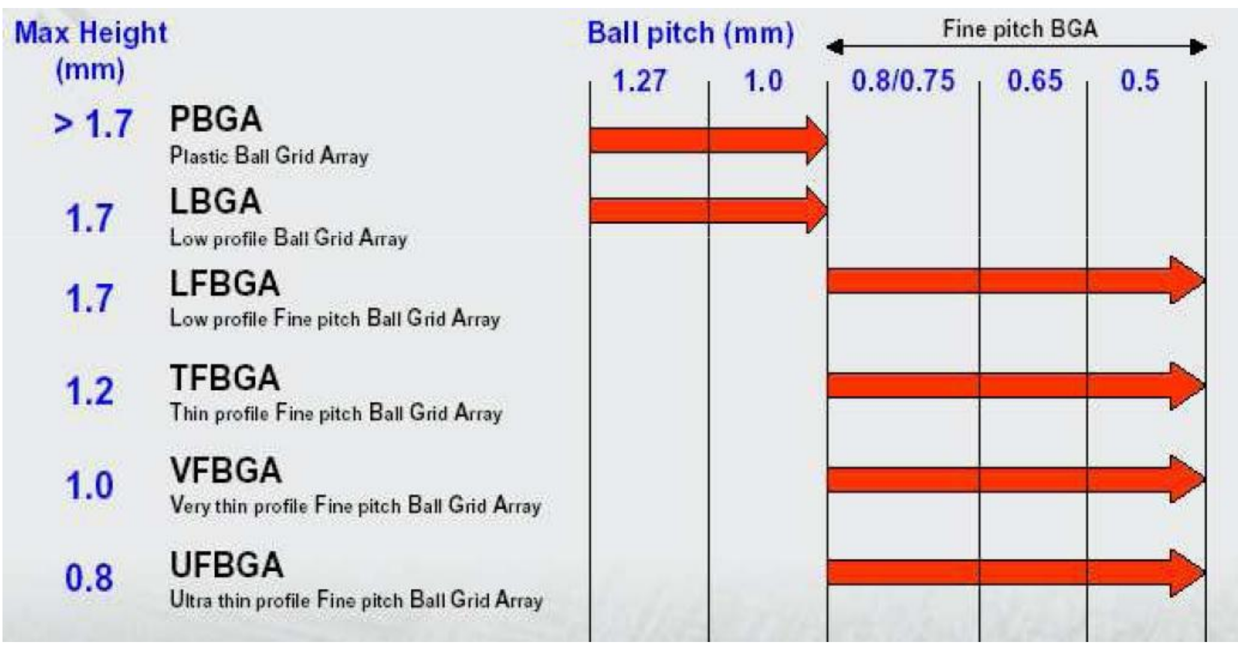


Fig. 0.19 BGA Family

The BGA package needs a higher complexity PCB (multi-layer PCB) because of the several rows of contact.

Identifying of types and Special cases

The component identification process starts with the function and type of package explained above. New technologies in BGA packages include specially involved Flip-

Chip packages, Package-on-Package (PoP), and Package-in-Package (PiP) which are mostly used in processor devices.

The Flip-Chip package is a face down technology which uses conductive bumps that are deposited directly on the die surface. These bumps provide a mechanical and electrical connection to the carrier or substrate.

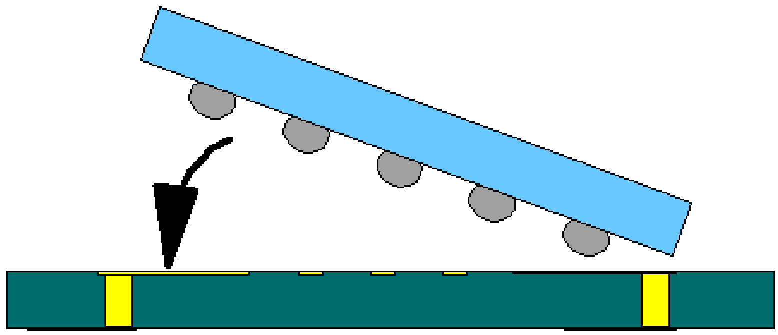


Fig. 0.20 Flip-Chip Principle

A special case of Flip-Chip BGA is the underfill BGA. It consists of injecting an epoxy resin under the device after it is soldered to the PCB. It is mainly used to compensate the thermal mismatch between the die (4 ppm/°C) and the PCB (16 ppm/°C).

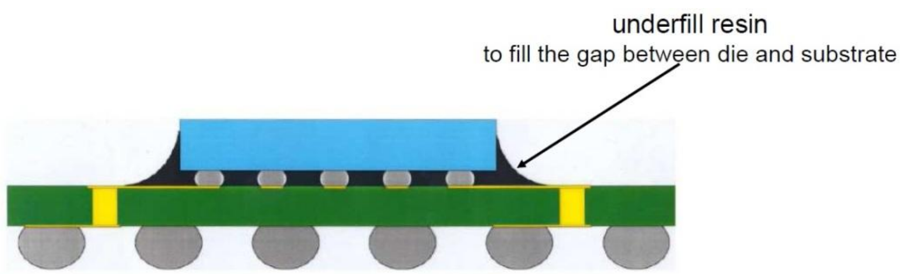


Fig. 0.21 Flip-Chip with UNDERFILL

A Flip-Chip underfill package will then be finally molded.

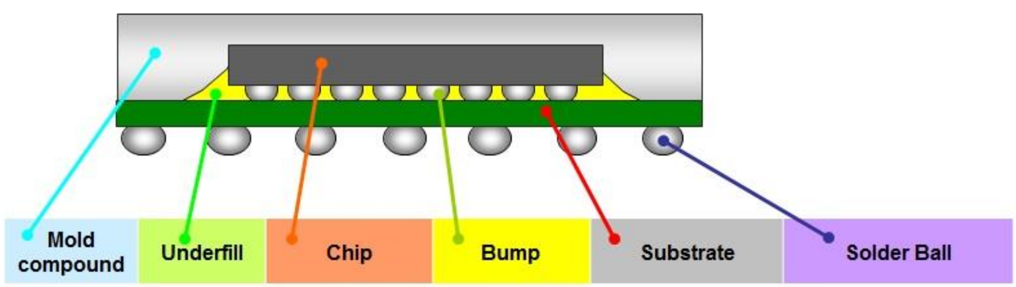


Fig. 0.22 Flip-Chip package (UF + Mold) Diagram

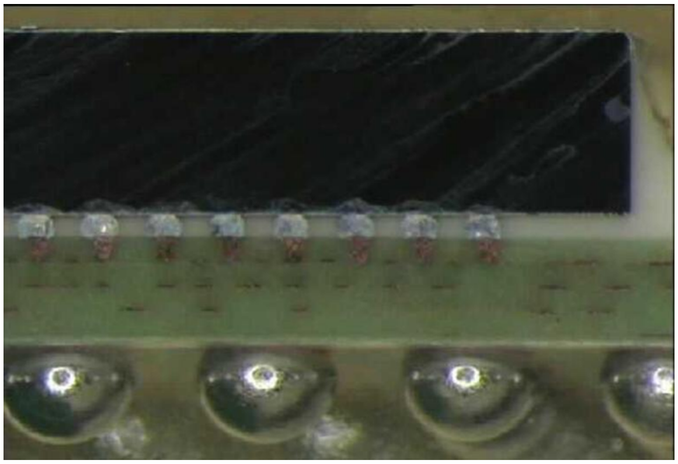


Fig. 0.23 Flip-Chip package (UF + Mold) Real

A PiP package is also known as a 3D package, Multi-Chip Module (MCM) or stacked package. It can combine flip-chip and wire bonding connections with multiple stacked chips all in one molded package. PiP packages reduce package area, improve signal speed and reduce fabrication costs.

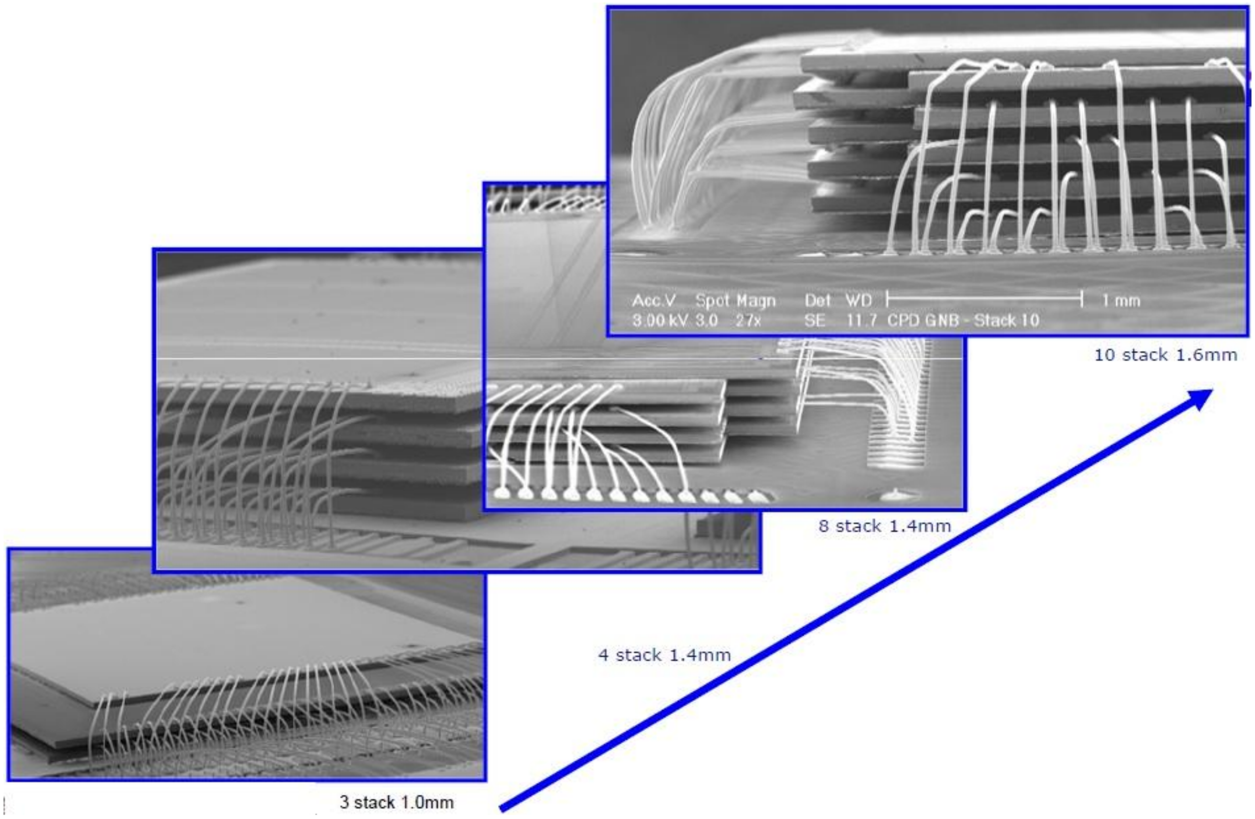


Fig. 0.24 PiP Evolution 2007 - 2012 (STMicroelectronics)

PoP packaging is a type of package which holds a package on top of another package with connections to route the signals between them. This type is also referred to as a stacked package. This configuration allows higher component density and is usually used in two configurations: memory stacking (two or more memories stacked) or logic memory stacking (CPU package on bottom and memory package on top).

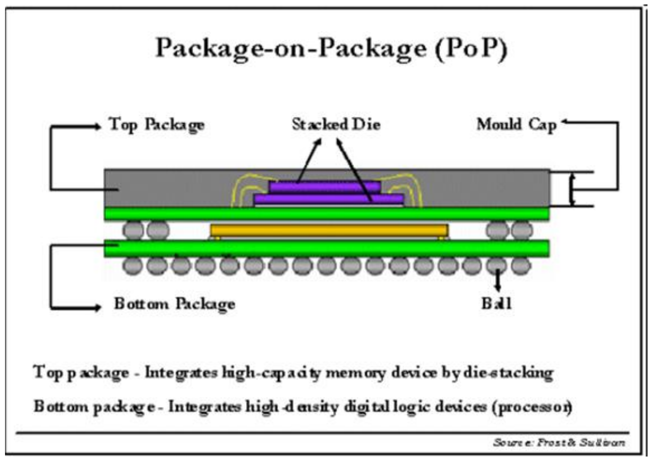


Fig. 0.25 PoP Package WB BGA on FC BGA (Frost & Sullivan)

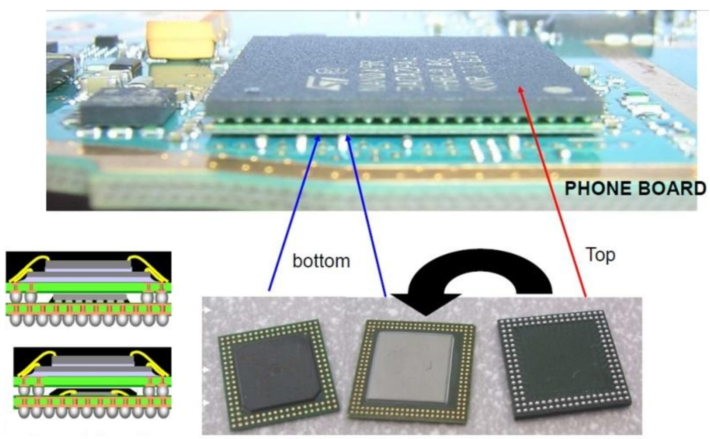


Fig. 0.26 PoP Package PCB Mounting (STMicroelectronics)

Measuring manufacturer parameters

A list of parameters is extracted from the package including dimension or material as detailed on section 3.1. Complete manufacturer parameters will be obtained during different stages of the component analysis to obtain the cost of production. These parameters are set by the importance of a component to a manufacturer and will affect directly its cost. All of these parameters will be collected in every single step of the component analysis in a specific order, and with no chance to be obtained after a sequential analysis continues.

REF	SUBSTRATE / DEVICE DATA FOR QUOTATION
A1	Device body size (in mm) : a X b mm
A2	Device number or ball (BGA) or land (LGA)
A3	Device pitch of ball (BGA) or land (LGA)
A4	Number of ball row for I/Os = rows having most of balls independent from each other. (start with peripheral rows, insert a "+" in case there is an empy rows of balls)
A5	Package Type : Standard WB (stack included) or POP WB
B1	Substrate Technology (Structure) : 2L PTH or 2L VIP or 4L PTH or 4L HDI 1-2-1
C1	Drill 1 (M1 to M2) : Copper Filled Yes / No
C2	Drill size 1 (M1 Land diameter / Min. Drill diameter / M2 Land diameter)
C3	Drill 2 (Top Micro Via 4L HDI only : M1 to P1) : Copper Filled Yes / No
C4	Drill size 2 (M1 Land diameter / Min. Drill diameter / P1 Land diameter)
C5	Drill 2bis (Bottom Micro Via 4L HDI only : M2 to P2) : Copper Filled Yes / No
C6	Drill size 2bis (M2 Land diameter / Min. Drill diameter / P2 Land diameter)
C7	Drill 3 (Buried Via 4L HDI only : P1 to P2) : Copper Filled Yes / No
C8	Drill size 3 (P1 Land diameter / Min. Drill diameter / P2 Land diameter)
C9	Drill type 3 : Buried PTH or Buried VIP
C10	Drill Stacking (4L HDI Only), only valid in case Drill 3 is copper filled : Yes / No
D1	Minimum Trace pitch (M1 / M2 metal layers)
D2	Minimum Trace pitch (P1 / P2 metal layers)
E1	Bonding Finger Minimum Pitch (M1)
E2	Bonding Finger Minimum Metal Width (M1)
E3	Wire Diameter (25um / 23um / 20um / 18um / 15.5um)
F1	No Plating line technology (or etch-back) used : Yes / No
F2	Bonding Finger Metal finishing : NiAu or NiPdAu
G1	Copper Layer Metal thickness (M1 / P1 / P2 / M2)
	OPTIONNAL (CAN BE USEFULL IN SOME CASES)
H1	Package Assembly Company & Plant
I1	Thickness of dielectric 2L (metal to metal) : M1 to M2
I2	Thickness of dielectric 4L (metal to metal) : M1 to P1
I3	Thickness of dielectric 4L (metal to metal) : P1 to P2
I4	Thickness of dielectric 4L (metal to metal) : P2 to M2
J1	Ball Pad Metal Finishing, presence of Nickel layer : Yes / No

Fig. 0.27 Required Substrate Parameters WB only

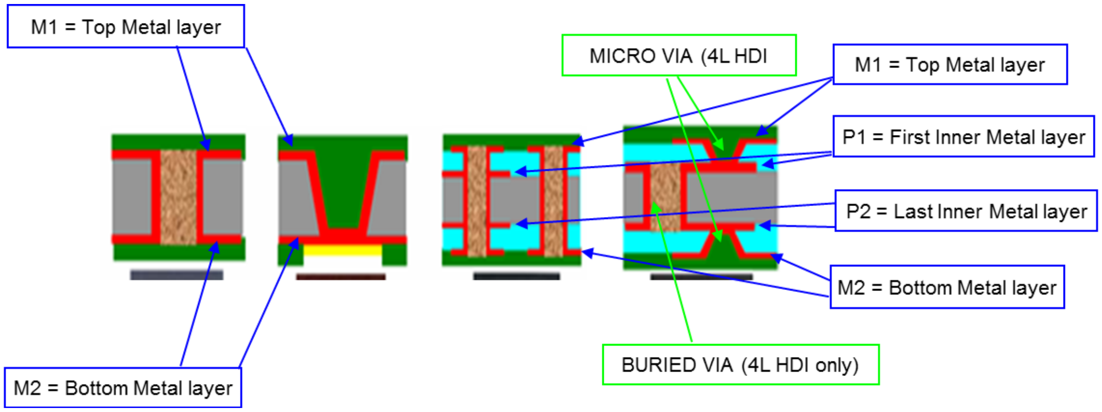


Fig. 0.28 Specific 2L &4L Substrate description and definitions (STM)

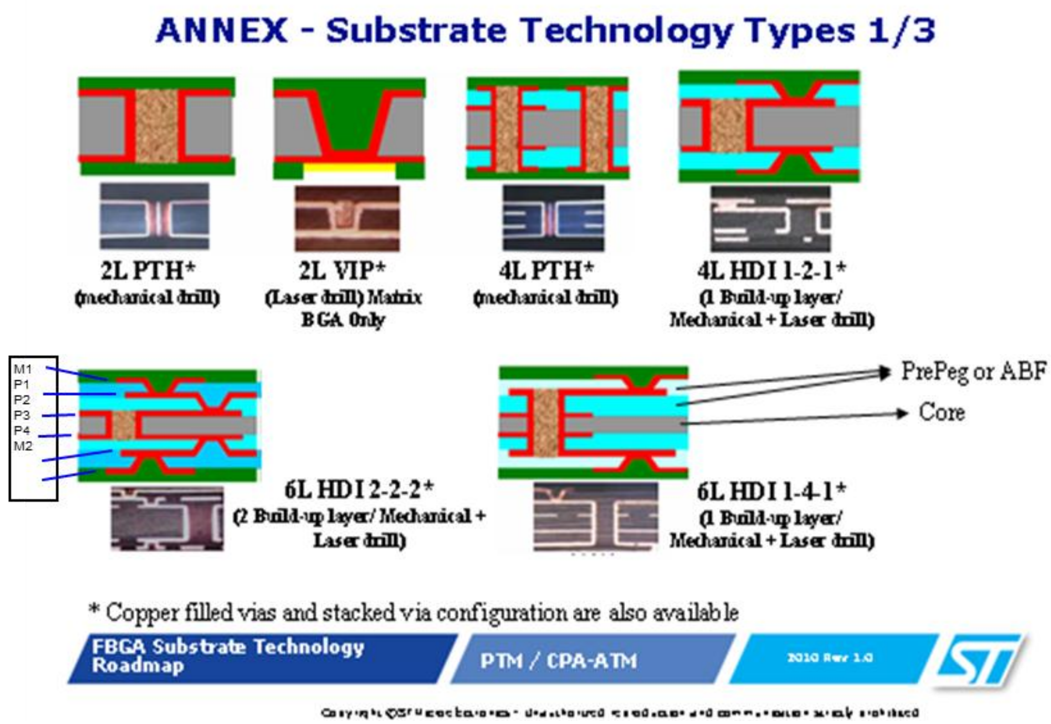


Fig. 0.29 Generic Substrate Structure description and definitions (STM)

An example analysis from the MediaTek component MT6223 is shown below:

- General physical measurements
    - A1: **9mm x 9mm**
    - A2: **225 balls**
    - A3: **500um**
    - A4: **4++2**

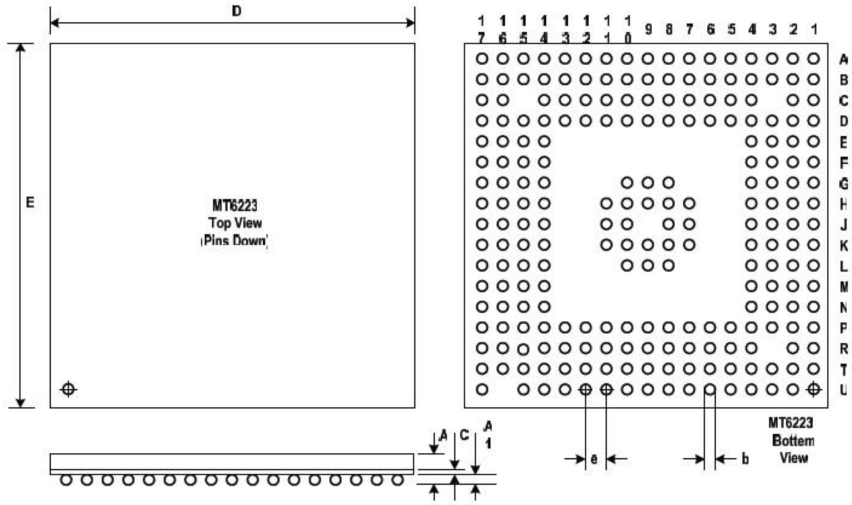


Figure 4 Outlines and Dimension of TFBGA 9mm*9mm, 224-ball, 0. 5 mm pitch Package

Body Size		Ball Count	Ball Pitch	Ball Dia.	Package Thk.	Stand Off	Substrate Thk.
D	E	N	e	b	A (Max.)	A1	C
9.0	9.0	224	0.5	0.275	1.2	0.21	0.36

Table 1 Definition of TFBGA 9mm*9mm, 224-ball, 0.5 mm pitch Package (Unit: mm)

Fig. 0.30 MT6223 Parameters

- X-Ray analysis
  - A5: **WB**
- Cross cut Analysis
  - B1: **2L VIP**
  - C1: **NO**

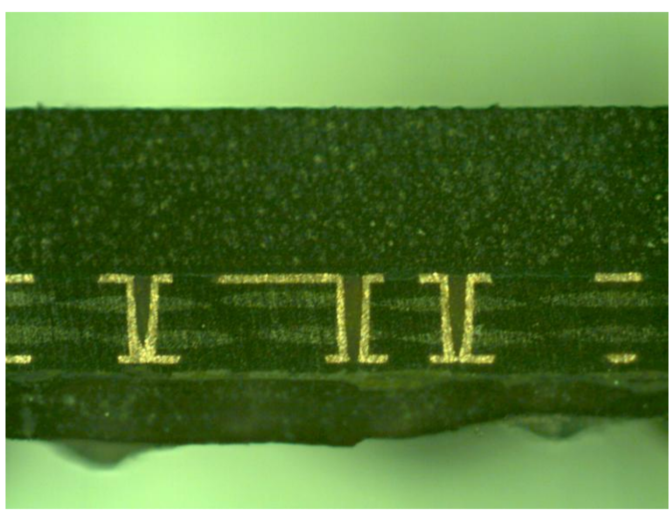


Fig. 0.31 MT6223 Cross cut

- C2: **100um / 189.25um**

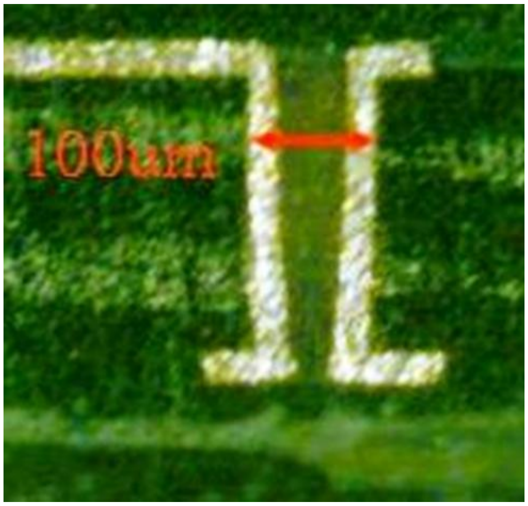


Fig. 0.32 Drill Diameter

Fig. 0.33 MT6223 Smallest Land

- Chemical Lab. Decapsulation
  - D1: **40.39+72.42= 112.81um**
  - E1: **140um**
  - E3: **15.5um**
  - F1: **NO**
  - F2: **NiAu**

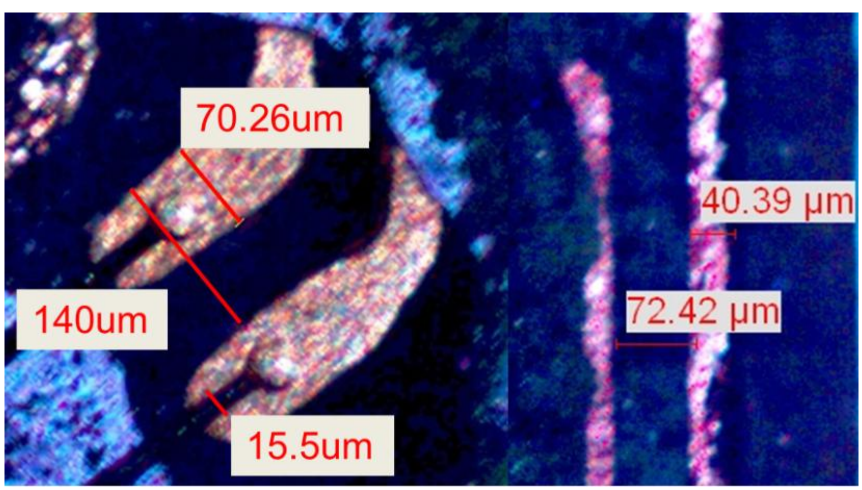
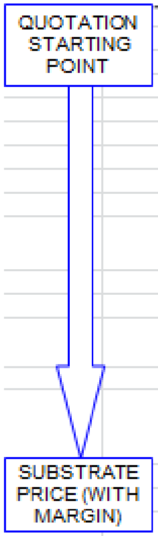


Fig. 0.34 MT6223 Substrate Cost Parameters

Due to the fact that the substrate analysis has given multiple costs, the most expensive one will be chosen. In this case: $0.0816 USD per substrate.



A5	STANDARD WB (STACK WB & Multi Chip WB INCLUDED), Not POP WB											
B1	2L PTH / 2L VIP											
C1	No				Yes		No or Yes					
D1	D1 = > 80						D1 = > 60		D1 = > 50		D1 = > 36	
E1 / E3	E1 = > 120 / E3 = 25 or E1 = > 115 / E3 = 23 or E1 = > 110 / E3 = 20 or E1 = > 105 / E3 = 18 or E1 = > 100 / E3 = 15.5						120 > E1 = > 110 / E3 = 25 or 115 > E1 = > 105 / E3 = 23 or 110 > E1 = > 100 / E3 = 20 or 105 > E1 = > 95 / E3 = 18 or 100 > E1 = > 90 / E3 = 15.5		110 > E1 = > 100 / E3 = or 105 > E1 = > 95 / E3 = or 100 > E1 = > 90 / E3 = or 95 > E1 = > 85 / E3 = or 90 > E1 = > 80 / E3 =		95 = > E1 / E3 = 25 or 90 = > E1 / E3 = 23 or 85 = > E1 / E3 = 20 or 80 = > E1 / E3 = 18 or 75 = > E1 / E3 = 15.5	
C2	(min. (Land M1 or Land M2)-Drill)/2 = > 70		(min. (Land M1 or Land M2)-Drill)/2 = > 60				(min. (Land M1 or Land M2)-Drill)/2 = > 50		(min. (Land M1 or Land M2)-Drill)/2 = > 40		(min. (Land M1 or Land M2)-Drill)/2 = > 40	
F1 / F2	No / NiAu or Yes /	Yes / NiAu	No / NiAu or Yes /	Yes / NiAu	No / NiAu or Yes /	Yes / NiAu	No / NiAu or Yes /	Yes / NiAu	No / NiAu or Yes /	Yes / NiAu	No / NiAu or Yes /	Yes / NiAu
Indication on A3 / A4	Usually : 0.5 p / 3 rows I/O		Usually : 0.5 p / 4 rows I/O				Usually : 0.4p / 3 to 4 rows I/O or 0.5p / > 4 rows I/O		Usually : 0.4p / > 4 rows I/O		Usually : 0.4p / > 4 rows I/O	
(US$) vs A1 Body size											price may be higher as new techno	be higher as new techno
3x3	0.0064	0.0082	0.0076	0.0093	0.0099	0.0117	0.0105	0.0123	0.0123	0.0140	0.0175	0.0193
3x5	0.0107	0.0136	0.0126	0.0156	0.0165	0.0194	0.0175	0.0204	0.0204	0.0233	0.0292	0.0321
3.4x3.4 or 3.5x3.5 or 3.6x3.6	0.0088	0.0112	0.0104	0.0128	0.0136	0.0160	0.0144	0.0168	0.0168	0.0192	0.0240	0.0264
3.5x4	0.0099	0.0126	0.0117	0.0145	0.0154	0.0181	0.0163	0.0190	0.0190	0.0217	0.0271	0.0298
4x4	0.0112	0.0143	0.0132	0.0163	0.0173	0.0204	0.0183	0.0214	0.0214	0.0244	0.0305	0.0336
4.5x4.5 or 4.6x4.6	0.0144	0.0184	0.0171	0.0210	0.0223	0.0263	0.0236	0.0276	0.0276	0.0315	0.0394	0.0433
5x5	0.0175	0.0223	0.0207	0.0255	0.0270	0.0318	0.0286	0.0334	0.0334	0.0382	0.0477	0.0525
5x7.5	0.0263	0.0334	0.0310	0.0382	0.0406	0.0477	0.0430	0.0501	0.0501	0.0573	0.0716	0.0788
6x6	0.0258	0.0328	0.0305	0.0375	0.0398	0.0469	0.0422	0.0492	0.0492	0.0563	0.0703	0.0773
7x7	0.0337	0.0429	0.0398	0.0490	0.0520	0.0612	0.0551	0.0643	0.0643	0.0735	0.0918	0.1010
8x8	0.0458	0.0583	0.0542	0.0667	0.0708	0.0833	0.0750	0.0875	0.0875	0.1000	0.1250	0.1375
8x8.5	0.0471	0.0600	0.0557	0.0686	0.0729	0.0857	0.0771	0.0900	0.0900	0.1029	0.1286	0.1414
9x9	0.0528	0.0672	0.0624	0.0768	0.0816	0.0960	0.0864	0.1008	0.1008	0.1152	0.1440	0.1584
10x10	0.0770	0.0980	0.0910	0.1120	0.1190	0.1400	0.1260	0.1470	0.1470	0.1680	0.2100	0.2310
11x11	0.0770	0.0980	0.0910	0.1120	0.1190	0.1400	0.1260	0.1470	0.1470	0.1680	0.2100	0.2310
12x12	0.1031	0.1313	0.1219	0.1500	0.1594	0.1875	0.1688	0.1969	0.1969	0.2250	0.2813	0.3094
13x13	0.1203	0.1531	0.1422	0.1750	0.1859	0.2188	0.1969	0.2297	0.2297	0.2625	0.3281	0.3609
14x14	0.1444	0.1838	0.1706	0.2100	0.2231	0.2625	0.2363	0.2756	0.2756	0.3150	0.3938	0.4331
15x15	0.1571	0.2000	0.1857	0.2286	0.2429	0.2857	0.2571	0.3000	0.3000	0.3429	0.4286	0.4714
16x16	0.1833	0.2333	0.2167	0.2667	0.2833	0.3333	0.3000	0.3500	0.3500	0.4000	0.5000	0.5500

Fig. 0.35 substrate Cost Analysis

A force of bonding test is also applied to the package once it has been decapsulated. A machine will use a thin pin to catch and pull a bonding until it breaks and measures the force needed. Types of breaks in the bondings will also be considered as grade (1 Balloff, 2 Ballneck Break, 3 Wire Break, 4 Fingeroff and 5 Finger Break). Each die bonding to the substrate or with another die will be subject to this test.

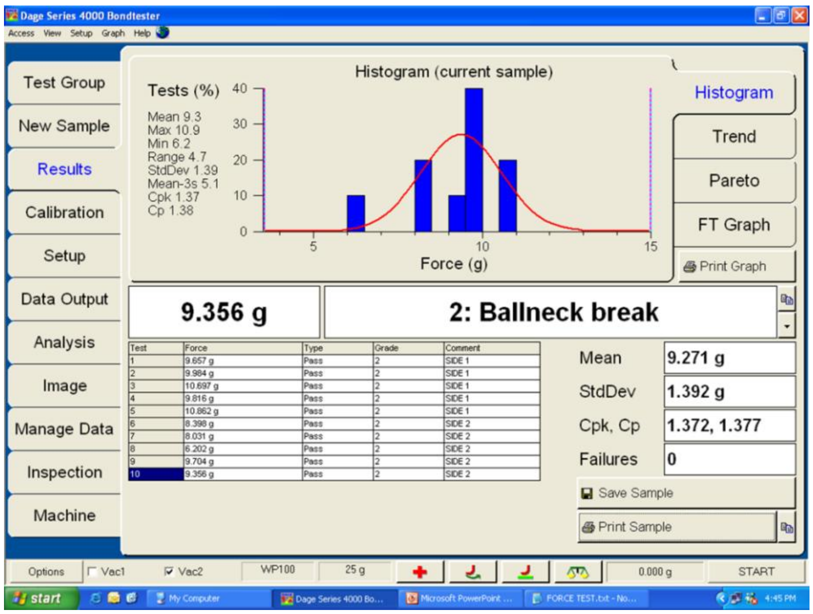


Fig. 0.36 BondTest Histogram

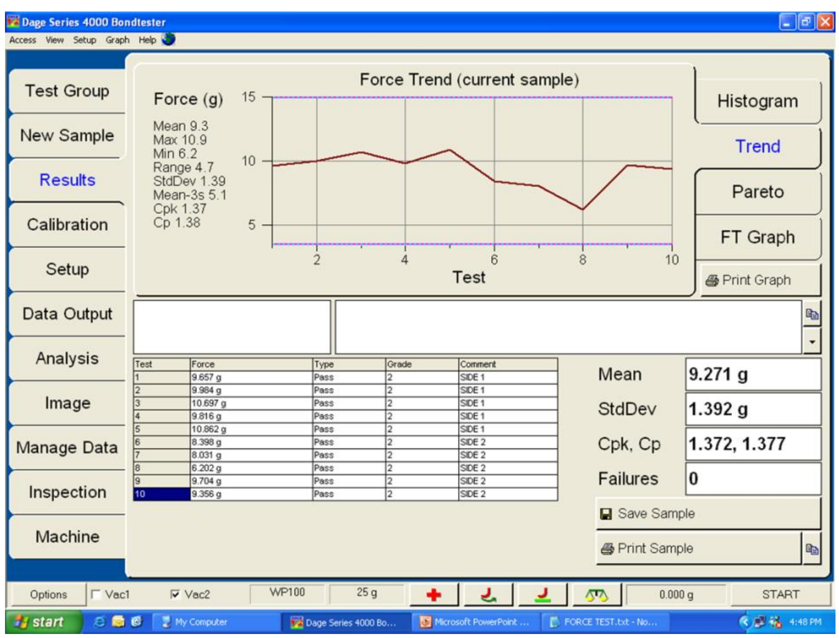


Fig. 0.37 BondTest Trend

Die

After the decapsulation of the package, the type of wire bonding material can be identified by color. The most frequently used is gold (yellow) because of its conductivity properties. Die width will be measured after a cross cut picture is taken. For a CSP the width will be the same as the package. In the chemical process the balls or bumps will be removed according to the type of package using the proper chemical method.

Type of die

Package dies can be either connected to the substrate by wire bonding or bumps in a Flip-Chip die. Bonded dies are very thin and fragile so manipulation is often done by vacuum pens. On the other hand, Flip-Chip dies are wider and easier to manipulate. Similar to packages, the main objective is to reduce the area by compressing the die as much as possible and will be reflected in the area of the package and later on in the volume of the device.

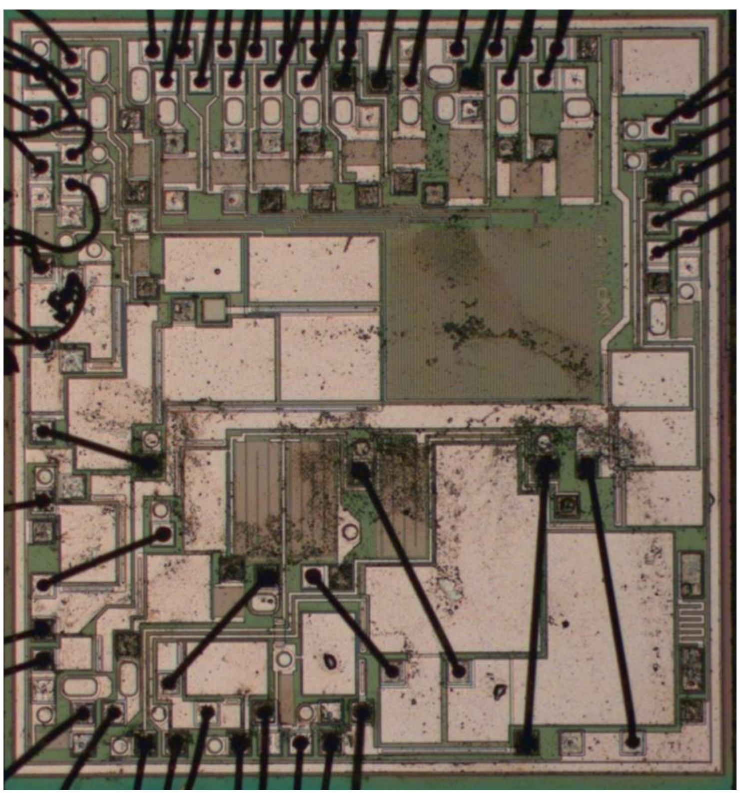


Fig. 0.38 Die with Wire Bondings

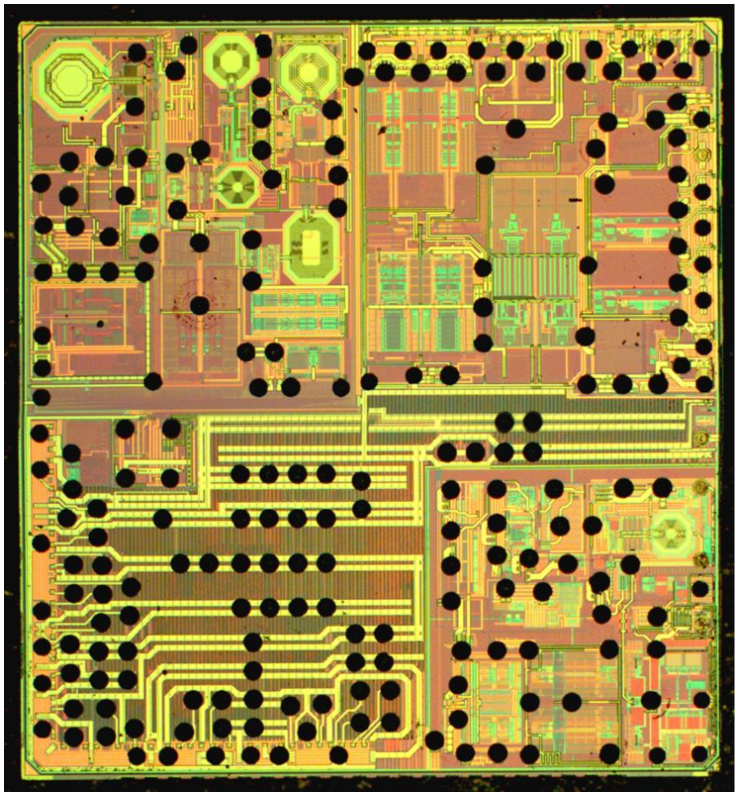


Fig. 0.39 Qualcomm Flip-Chip Die QTR8200

Critical parameters

In addition to the final cost of production, calculation parameters such as die pads, dimensions, and markings are necessary for evaluation and comparisons.

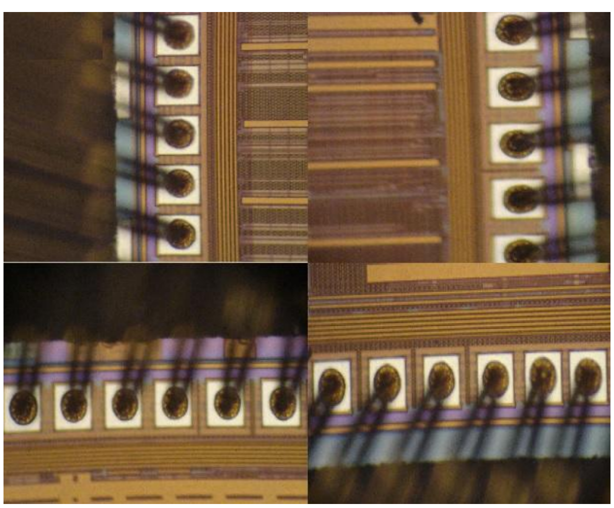


Fig. 0.40 Die Pads

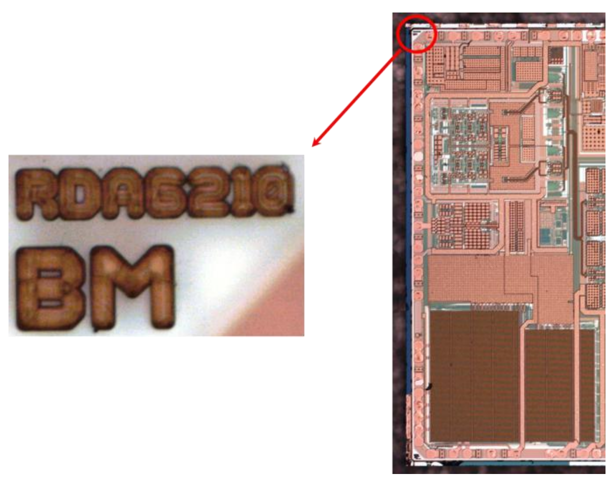


Fig. 0.41 RDA6210 Die Marking

For cost evaluation in a WLP it is important to recognize the type of package: WLCSP (Fan-In) or eWLP (Fan-Out). For Fan-Out there are no tools for cost estimation because technology estimates are out of our hands. For Fan-In, an equivalent in-House technology is used.

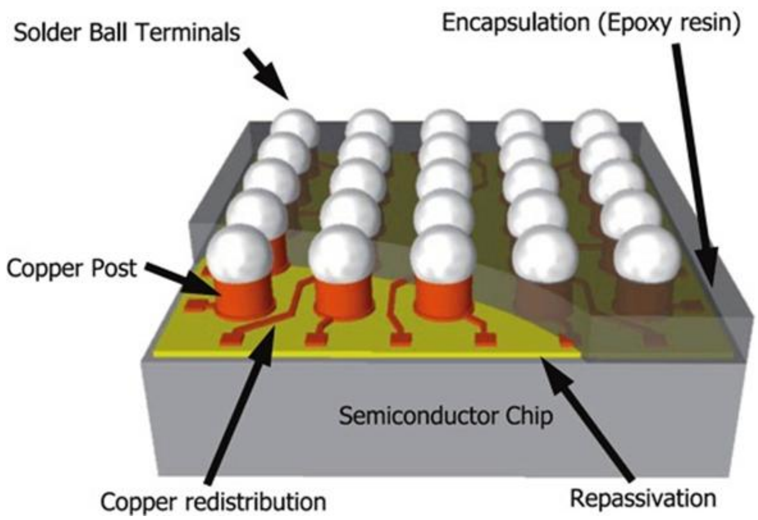


Fig. 0.42 FAN-IN WLP

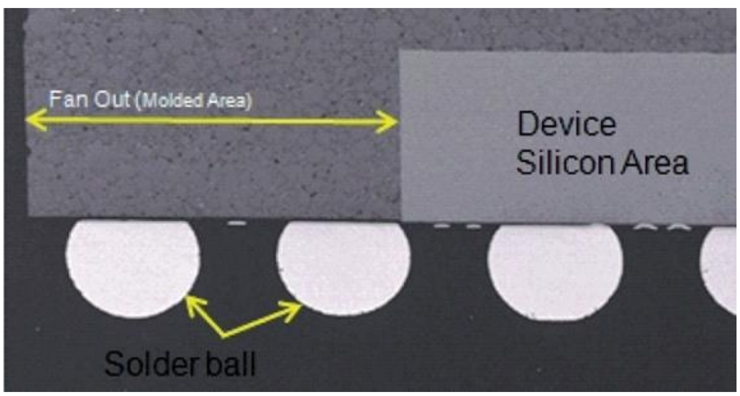


Fig. 0.43 FAN-OUT WLP

A Focused Ion Beam (FIB) Analysis is requested from the Failure Analysis (FA) department to obtain the technology of die. The wafer size depends on die dimensions and technology.

Two total costs will be given, Front-End cost and Back-End cost.

For the Front-End cost simply divide the cost of the wafer (standard 8-inch $198 and 12-inch $264) by the number of dies per wafer.

For the Back–End cost it is necessary to obtain the “Over Cost Coefficient”, (refer to Fig. 3.44) based on the number of dies, and multiply it times 0.04.

The Over Cost Coefficient states that the more pieces produced, the cheaper the cost of production.

Number of Die per WAFER	Over cost coefficient
< 3000	x 1.88 (88%)
3000-4000	x 1.72 (72%)
4000-5000	x 1.61 (61%)
5000-8000	x 1.44 (44%)
8000-20000	x 1.24 (21%)
>20000	x 1 (0%)

Fig. 0.44 Over Cost Coefficient Table

The final price per unit will be the sum of both.

For the Qualcomm WCD9310 Audio Codec with die dimensions 4mm x 3mm, the cost is calculated as following:

Cost details die 1

Equivalent process technology	CMOS065, 12-inch			
Wafer cost	2575 $	2575		
DO	0.06	0.06		
Die Area	12.06 mm²	12.06		
Dies per wafer/silicon cost	5,400		$ 0.48	$ 0.48

Fig. 0.45 WLP Cost details (dimension)

Wafer 12-inch = $264 USD.

Divide $264 / 5400 = $0.0489 USD (Front-End Cost)

1.44 x 0.04 = $0.0576 USD (According to Fig. 3.44 the coefficient is 1.44)

$0.0489 + $0.0576 USD = $0.1065 USD (Final cost per package)

CHAPTER 4 - CONCLUSIONS

Company's interest on the benchmark activity

ST-Ericsson's interest in competition analysis is based on the importance of product challenges, technology and material improvements, as well as manufacturing, marketplace and customer changes. Evolution is the main and most influential factor in semiconductor companies. Competition has increased complexity in all areas. To analyze and understand these new technologies gives ST-Ericsson an approach to establish a roadmap for future components and packages. With new materials being introduced in the manufacturing processes competitors are improving their products. All phases of the business are becoming more complex. Reliability and R&D engineer's activities are much more complex, much more challenging and therefore much more exciting.

To understand the connectivity between components and a detailed study of each one of them provides crucial information to accelerate innovation and improve existing technologies and solutions through fast and efficient product analysis and technology construction analysis.

By establishing a new Software benchmark procedure, to be able to compare similar devices in different parameters such as: Browser, CPU, connectivity, JAVA, User interface, Memory and graphics, ST-Ericsson improves the capability to develop a better interface and co-existence between components.

Influence of semiconductor technology knowledge

The study of a competitive device and package will allow readers the understanding of the general operation of a mobile device. Starting from it software characteristics up to its hardware components, it involves every step from the technology used in the die to the type of package and its materials. All this information will let STMicroelectronics and ST-Ericsson offer strategic independence to all of their partners worldwide as a semiconductor supplier offering the best technology at the best price. Reducing package area involves reducing PCB manufacturing costs.

Semiconductors are found nowadays in everyday life products or machines used. From the moment we open our eyes electronic equipment is present to make life simpler; from the alarm clock to wake up in the morning, to the Set Top box when watching TV before bed. Having an understanding of the technologies involved when manufacturing companies are developing a semiconductor will let us comprehend how they are run and how we as customers can adapt more effective products to our specific needs.

In the professional point of view this analysis of device structure, fabrication processes and package design knowledge allows us to:

- Understand the intellectual property and technology strengths of the competitors to enable differentiation in property products and guide important technical design decisions.
- Understand the cost structure of components to determine competitive device price.
- Understand quality and performance of competitors to be improved upon by ST-Ericsson.

By obtaining the cost of production of a component and its features established different departments of design and development of ST-Ericsson are able to evolve the roadmap of the company reaching new and more capable state-of-the-art devices, at a lower price than the competition.

Manufacturing processes are also affected while new technologies evolve. Along this paper evolution of technology has showed how size reduction has affected price production and at the same time increasing features. That is the most important goal of a semiconductor company and in this paper is explained how they reach this goal.

GLOSSARY

Important terms

Benchmark: a method of analyzing the performance of a system and/or component.

Fabless company: a company that designs and sells but does not fabricate a component.

Semiconductor: material that is either a good conductor or a good insulator depending on variables such as heat, light or voltage.

Smartphone: phone with processing capabilities and connectivity more advanced than basic phones.

EDGE (Enhanced Data rates for Global Evolution) is a technology being promoted by the TDMA and GSM communities that is capable of both voice and 3G data rates up to 384 Kbps. The standard is based on GSM standard and uses TDMA multiplexing technology.

W-CDMA (Wideband Code Division Multiple Access) is a third-generation (3G) wireless technology that supports high-speed data transmission (144 Kbps to 2 Mbps), always-on data service, and improved network capacity (more people can use each tower at the same time) in GSM systems by using CDMA instead of TDMA. The version of WCDMA used by NTT DoCoMo in Japan is called FOMA or J-WCDMA; the European version is referred to as UMTS, E-WCDMA, or MT-2000 Direct Spread. W-CDMA is a competitor to cdma2000.

UMTS (Universal Mobile Telecommunications System) is a third-generation wireless communications technology and the next generation of GSM (Global System for Mobile Communications). UMTS is a wireless standard approved by the International Telecommunications Union (ITU) and is intended for advanced wireless communications. UMTS promises high-speed mobile data (up to 2 Mbps) and advanced multimedia capabilities such as streaming video.

HSPA (High Speed Packet Access) is the joining of two phone protocols that improves the performance in the 3rd generation mobile communications.

GPRS (General Packet Radio Service) is a next generation (2.5G) technology standard for high-speed data transmission over GSM networks. GPRS sends data over packets rather than via circuit switch connections on cellular networks which allows for "always on" wireless data connections and speeds up to 115Kbps.

GPS (Global Positioning System) is a system of 24 satellites, computers, and receivers that is able to determine the latitude and longitude of a receiver on Earth. By triangulation of signals from three of the satellites, a receiving unit can pinpoint its current location anywhere on earth to within a few meters.

GSM (Global System for Mobile Communications) is a type of digital wireless network that has been widely deployed throughout the world. There are 4 primary frequencies in use today: 850MHz, 900MHz, 1800MHz and 1900MHz. In Canada and the United States, you will find support for the 850, 1800 and 1900MHz bands, while most countries in Europe and Asia support either 900, 1800 or 1900MHz.

CDMA (Code Division Multiple Access) is a type of digital wireless technology that allows large amounts of voice and data to be transmitted on the same frequency. CDMA is second-generation cellular technology (2G) and is currently available in Canada, the United States, Pacific Asia, and Latin America. Most CDMA service providers (Telus Mobility and Bell Mobility for example) will migrate to a high-speed data technology called 1xRTT.

LTE (Long Term Evolution) is a standard for wireless communication of high-speed data.

BT (Bluetooth) is a wireless personal area network (PAN) specification that connects phones, computers, appliances, etc… over short distances without wires by using low power radio frequencies.

WLAN (Wireless Local Area Network) is a network that transmits and receives data over the air using radio frequency technology, minimizing the need for wired connections. A wireless LAN can serve as a replacement for or extension to a wired LAN.

ROADMAP is a plan of short and long term goals with specific technology solutions.

Abbreviations

R&D (Research and Development)

3GPP (3rd Generation Partnership Project)

3GPP2 (3rd Generation Partnership Project 2)

DBB (Digital Baseband)

NAND Main Flash Memory

SDRAM (Synchronous Dynamic Random Access Memory)

PMU (Power management unit)

PDA (Personal Digital Assistant)

AE (Application Engine)

AP (Application Processor)

PCB (Print Circuit Board)

SAW Filter (Surface Acoustic Wave Filter)

SoC (System on Chip)

IC (Integrated Circuit)

MCP (Multi-Chip Package)

CMOS Technology (Complementary Metal-Oxide Semiconductor Technology)

CPU (Central Processing Unit)

GPU (Graphic Processing Unit)

BDB (Benchmark Data Base)

SMD (Surface Mount Device)

UF (Underfill)

MCM (Multi-Chip Module)

PiP (Package in Package)

PoP (Package on Package)

WLP (Waffer Level Package)

SOP (Small Outline Package)

QFP (Quad Flat Package)

QFN (Quad Flat No-lead)

DFN (Dual Flat No-lead)

WLCSP (Wafer Level Chip Scale Package)

BGA (Ball Grid Array)

Wi-Fi (Wireless Fidelity)

BOM (Bill of Materials)

CSP (Chip-Scale Package)

FIB (Focused Ion Beam)

FA (Failure Analysis)

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